PRESIDENTIAL ADDRESS

by

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Notes on the History of Foundation Engineering

" He who considers things in their first growth or origin will obtain the clearest view of them "—Aristotle.

He would be less than human who did not find pleasure in the honour which you have done me this evening, and who did not approach the task of being your President with trepidation and even anxiety. I can do no more, however, than thank you sincerely for placing such confidence in me, and assure you that I shall ever be conscious of the honour and of the dignity of my office. I shall seek to discharge my duties to the best of my ability and with the object of promoting the science and art of Structural Engineering to which this Institution is committed. I have high standards to live up to ; I hope that in a year's time I may have been enabled to pass on the seals of my office with undiminished lustre.

It used to be the custom for a new President to address the members of the Institution on the subject with which he had been most closely connected during his professional career. With the passing years this custom has changed and in recent times Presidents have felt free to address members on a topical subject, or a subject of special or particular interest.

Naturally, I have had the matter under consideration for some time, and it has seemed to me that there could be some advantage if I sought to direct your attention to a subject which has always had for me a special attraction. Not that I should claim any particular ability in putting it before you, but rather would I hope to kindle in you a like interest and enthusiasm. I refer to the science and art of Foundation Engineering.

It may not be entirely out of place here to remark that the exhibition which was held in London this summer, and which shewed a great many types of equipment now available to Engineers, was in some measure a commentary upon foundation engineering, for I had no sooner decided upon my subject than I began to discover that foundation engineering is bound up largely with the equipment available for carrying out the work. Thus it will follow that this Address will refer often to equipment—which, perhaps, is not entirely inappropriate for one who commenced his professional life with a large firm of contractors, and who acquired a love for foundation techniques at the bottom of a deep excavation.

It will be within the knowledge of most members of this Institution that the motto on our crest is *Fundamento Semper Stabili*. I have toyed with these three words in an effort to render them into satisfactory modern English, and no translation seems to me to be more appropriate than " Always on a Sure Foundation." Some may question this translation, but if it is anywhere near the truth I suggest it is at least an excuse for taking as my subject " Foundation Engineering."

Fig. 1—Block of flats in Italy

An old authority wrote as follows :—

> " the most refined elegance of taste as applied in the architectural embellishment of the structure, the most scientific arrangement of the spans and disposition generally of the superior parts of the work, and the most judicious and workmanlike selection and subsequent combination of the whole materials composing the edifice, are evidently secondary to the grand object of producing certain firm and solid bases whereon to carry up to any required height the various pedestals of support for the structure."

Too often, however, it is a case of " out of sight, out of mind." The foundations are secondary—taken for granted—and what matters is that which is seen. What happens to what is seen when what is unseen is faulty, is well illustrated by the block of flats in Italy shewn in Fig. 1. The leaning tower of Pisa may not be entirely unfamiliar ; it is 13 ft. out of vertical in a height of about 175 ft. It was commenced about 1174 and completed about 1350 and the failure is said to be due to an inadequate foundation.

Fig. 2—Ziggurat near Babylon

The foundation of any structure has been variously defined. Some would refer to the artificial lowest part of the structure whilst others would regard the ground upon which the structure is supported as the foundation. One definition says " the ground-work or lowest part of a building which supports the other parts, as the foundation of a house, of a castle, of a fort, of a tower." Whilst I should generally regard the two parts, namely the ground and the structures as jointly forming the foundation, for the purposes of this evening's considerations, we must surely direct our thoughts to that which is artificially made and built. In this connexion it may be of interest to recall that Leon Battista Alberti (1404-1472) used to consider the foundation not as part of the structure itself but as an artificial support on which the structure was to be placed.

Although there are evidences of buildings as early as 4500 B.C. the earliest reference to a foundation which I have been able to find describes the mud-brick structures of Egypt in 3000 B.C.; in these the walls were reinforced with wooden beams and built off a stone foundation. The bricks, it seems, measured about 10 in. × 20 in. × 1½ in.

The great pyramid of Cleops (Khufu) in Egypt measured some 756 ft. × 756 ft. × 481 ft. high and is the only one of the seven wonders of the world which is still standing. It was built of nummulitic limestone. Herodotus records that it took 100,000 men 30 years to build. Nothing is said about the foundations, however, possibly because they were built off the solid rock.

It may be of interest to make reference to the ziggurats of Babylon, Fig. 2. These were temple towers known in 2500 B.C. and consisted of baked clay bricks bonded with bitumen mortar forming three or more terraces. At Ur the foundations measured 200 ft. × 150 ft. The Tower of Babel was probably such a structure. What is of interest here in connexion with the ziggurats is that little or no consideration seems to have been given to the foundations. On the other hand, in an attempt to counteract the dangers of shrinkage and uneven settlement, reeds were used as a kind of reinforcement. A good example of this technique has been revealed at the Cassite ziggurat at Agar Quf (*c.* 1200 B.C.) Fig. 3. Here at every five courses there is a layer of reed matting while the whole structure is tied together by heavy multiple cables of tough reeds running across from face to face. By way of contrast are the details of the foundation of a column in the Hypostyle Hall at Karnak in Egypt *c.* 1300 B.C. The foundation consisted of friable little blocks carelessly placed in a hole ; as a result of flooding, eleven such columns fell flat but they had lasted until November 1899, that is, over 3000 years. Although the building was built upon soft alluvial soil, little attention seems to have been paid to the foundations ; 2 ft. of sand is the basis of some of the largest walls.

The next earliest reference to a foundation which I have been able to find is in the Bible in the first book of Kings ch. 5 verse 17. There it is recounted how Solomon built the foundations of the temple in Jerusalem ;

> " And the king commanded, and they brought great stones, costly stones and hewed stones, to lay the foundations of the house."

This was about 1014 B.C. And in that same chapter you may read of the plans, the specification, the Bill of Quantities, the priced documents and the carrying out of the Contract, including the labour price etc.; a seven year Contract. And if you would look further, in 725 B.C. came Isaiah's prophecy

> " Behold, I lay in Zion for a foundation a stone, a true stone, a precious corner-stone, *a sure foundation.*" (Is. 28 : verse 16).

Beyond these and similar early references, little further on foundations is found until the approach of the Christian era. At this stage, there appeared the first text book on Architecture. The author, whose full name was Marcus Vitruvius Pollio and who was known as Vitruvius (date of birth about 75 B.C.) began his history with an account of the theatre of Dionysius at Athens. It seems that spectators were accommodated upon wooden benches in early times : in the year 500 B.C. the scaffolding or benches collapsed and this led to the development of a permanent stone structure. Specifications and drawings were common in 548 B.C. when the temple of Apollo at Delphi was rebuilt. An example of a 24 ft. span bridge built *c.* 500 B.C. is said to be in existence still at Bieda, north of Rome and shews that the vaulted form was then in use. The walls of such a city as Nineveh *c.* 600 B.C. might be provided with a foundation of limestone rubble. The name of Nebuchadnezzar (*c.* 700 B.C.) is to be found on old bricks laid in a primitive form of cement.

Vitruvius held an official position in the rebuilding of Rome by Augustus (27 B.C.-14 A.D.) and his book

Fig. 3—Reed reinforcement

was probably written before 27 B.C. at Jarrow (or Wearmouth) in England. After addressing the Caesar in extravagant terms, he states that Architecture consists of

> " Order, Arrangement, Proportion, Symmetry, Decor and Distribution."

He sets out the requirements for sites,

> " first to be healthy, free from clouds and hoar frost, away from marshes."

He then proceeds to describe the foundations of walls.

> " If such foundations can be found, they are to be dug down to the solid and in the solid as may seem appropriate to the amplitude of the work of a breadth greater than that of the walls which shall be above the ground ; and these foundations are to be filled with as solid structure as possible.'

It is of interest also to know that, apart from building, Vitruvius had lively ideas on Town Planning. Undoubtedly he was a master of report writing and seems to have had, besides a natural charm, considerable skill in getting his ideas over to his master. In addition, he seems to have possessed knowledge of his materials for he refers to many, e.g. bricks (which should be made from clay, not from sandy or chalky soil nor gravelly), sand (not to be obtained from the sea shore because it discharges the salt), lime (obtained by burning it out of white stone or lava), pozzuolana (a kind of powder which produces wonderful results), stone (some are soft, others medium, some hard) and timber (which is to be felled from the beginning of autumn).

> " Let the stone," said he, " be got out two years before, in summer but not in winter, and let it lie in exposed places. Those stones, which in this time are damaged by weathering, are to be thrown into the foundations."

About the first century B.C. and for some years later the commonest building material was concrete, not only in walls and foundations, but also in vaults, domes etc. Pozzuolana cement was used with an aggregate of broken puperin, tufa or brick. Pozzuolana cement was far superior to the lime mortar previously used by the Egyptians because it would harden under water. It consisted of a mixture of lime and volcanic ash from the lava of the crater of Sulphartara near Pozzualii now a suburb of Naples. It was extensively used for hydraulic works : baths at Caracalla, the Great Aqueduct, foundations of the Pantheon and the Colosseum were all constructed with pozzuolana cement.

It is significant that in the Middle Ages the cement used in northern Europe was a sand-lime mixture and that until the 19th century there was no successor to Vitruvius to lay down the proportions in a concrete.

Indeed, after the Roman occupation of Britain, bricks and tiles were not used and they were replaced by thatch and wooden shingles. The thatch was such a fire hazard, however, that in 1212 tiles were made compulsory for roofs.

In 1756 hydraulic cement was rediscovered. John Smeaton (1724-1792) of Leeds, an engineer who was engaged to build the third Eddystone Lighthouse, found that clayey limestone carefully burned and slaked would produce a substance which hardened under water. The mixture he used was a 1 : 2 : 4 concrete. In 1796 James Parker of Northfleet, Kent, discovered that any overburned naturally occurring material could be pulverised mechanically and he called it ' Roman cement ' ; this was the first artificial cement to be manufactured using naturally occurring materials. In 1810 came Edgar Dobby's patent for the manufacture of cement with artificial mixtures. But the credit for modern Portland cement, so named because the products closely resembled Portland stone, is usually given to Joseph Aspdin of Leeds for his material produced in 1824. Aspdin used high temperatures for burning to drive off the carbon dioxide. Later an American patent was granted to David O. Saylor in 1871. In 1828-32 Sir M. I. Brunel (1769-1849) used Aspdin's cement made at Rotherhithe for the Thames Tunnel, and for the first time combined concrete with tensile reinforcement. The term " concrete " is believed to have been introduced between 1820 and 1830. The name L. J. Vicat (1786-1861) appeared in 1812 in connexion with tests on the quality of cement ; H. L. Le Chatelier (1850-1936) is another name associated with tests on cement.

For the purposes of historical comparison, it may be noted that concrete was proposed for columns in 1862 by W. H. Wood and he patented the idea of filling a cast-iron column with concrete. T. Hyatt (1816-1901) introduced the idea of hoop reinforcement in 1878 but it was little used until about 1900 when A. G. Considère (1841-1914) developed the idea.

Cement with a high early strength was introduced about 1920 ; alumina cement was marketed in 1925, and low heat cement appeared about 1932. Sulphate resisting cement was produced about 1950.

In marshy districts and other places where there was neither rock nor reasonably firm ground to build upon, it seems that our building forefathers took elementary steps to improve the conditions. When the first attempt was made to build a tower at Ramsey, in the tenth century, the builders contented themselves with beating the ground as hard as they could " with frequent blows of rams " ; but when this had proved fatally insufficient and they had to start all over again, they dug a deep hole, which they filled with a mass of stones rammed tight and bound together with a strong mortar. At Bardfield Park in 1344 two men were employed, " making the place for the new house, and making a bridge over the water, and ramming (rammand') the foundations of the said house." References to ramming the ground are not infrequent.

We find for instance the following reference in L. F. Salzman's " *Building in England down to 1540* "—

> " Now the ground is made even with the rammer (Chelindro) now the irregularity of the surface is beaten down with frequent ramming (ariete cerebro), now the solidity of the foundation is tested (exploratur) with piles driven into the bowels of the earth. The height of the wall, built of cut stone and rubble (ex cemento et lapidibus), rises and soars according to the law of the level and plumbline (amussis et perpendiculi). The flatness of the surface of the wall is due to the smoothing and polishing of the mason's trowel (trullae)."

On the other hand, T. Hughes writing in about 1840 warned against beating or ramming the ground, and particularly London clay : he asserted that the remoulding effect is such that the bearing capacity is reduced by pounding rather than improved.

At Westminster in 1292 three carts were employed to carry gravel (gravellam) for foundations, while in 1532 the foundations of a brick wall were made of ' stone, flynte, chaulk and brick battes.' The orders for the rebuilding of Eton College Chapel, in about 1453, specified that

> " the first course of the ' growndes,' or footings, shall be of flat Yorkshire stone, carefully laid ; next a course of Yorkshire and Teynton stone mixed, and on this blocks of Teynton stone, ' heathstone,' and flints, set in ' good and myghty morter made with fyne stone lyme and gravell sande '."

Again at Winchester in 1258, 80 workmen were employed at the chalkpit for a week mining chalk for foundations, and at Nottingham in 1367 there is a record of 24 loads of 'fylling-stones' supplied for foundations.

In 1770 when the foundations of Newgate Prison were being prepared, the principal foundations were 40 ft. deep because the site was partly on the ancient ditch of the London wall. They then threw into the bog cartloads of whole and broken bricks and cartloads of 1 : 4 mortar. The stones were rammed in place and each layer grouted.

It would be a fair generalisation therefore to say that unless foundations were carried down to actual rock, the trench dug out would be filled to a variable depth with rough stones etc. to form a footing of somewhat greater breadth than the wall to be raised upon it.

In 1947 when a war-damaged building in St. Dunstan's Hill, Eastcheap, City of London, was being demolished, preparatory to rebuilding, it was discovered that the foundation of a flank wall some 70 ft. high consisted of chalk filling placed into the ground.

During recent months whilst reconstructing an office building in Mayfair, it has been found that the party wall with the adjoining building, some 70 ft. high appeared to have been based upon about 18 in. of clay or hoggin placed in a trench and supported upon some quite adequate and satisfactory gravel. This proved to be particularly exasperating as the chemical consolidation process applied to stabilise the gravel was effective in the gravel but not in the clay material. The buildings were erected 1730-1750. The calculated loading under the footing of this wall was nearly six tons/sq. ft. and settlement of some 2 in. appeared to have occurred. The chemical treatment proved of great value in supporting the sandy ground whilst the wall was underpinned by traditional methods.

In the light of modern conditions the following extract from the writings of John Wyclif *c.* 1360 may be of interest. Talking of the builders, he said :

> " They conspire together that no man of their craft shall take less for a day than they have agreed among themselves, although he should by conscience take much less, and that none of them shall do steady time work which might hinder the earnings of other men of their craft."

Writing in about 1847, Edward Cresy says that whatever the character of masonry, the first consideration should be the arrangement of the footings which should be constructed of stones as large as can be obtained. He says :

> " they should all be squared, brought to an equal thickness in the same course and laid upon their natural bed ; the foundations should consist of several courses each decreasing in breadth as they rise in proportion to the thickness and height of the intended wall."

He then refers to the practice of the Romans to include 'bond stones' passing through the entire thickness of the wall with a filling-in between the stretchers composed of rubble or small stones bedded in mortar, the excellence of which has rendered them remarkably durable.

According to Cresy, rock was the only 'unexceptional' foundation for hydraulic construction and even in this case it was necessary to ascertain whether the thickness was sufficient.

> " A soil composed of clay and gravel often forms a very compact bed upon which the masonry may be placed without pilings : but sand, peat and compressible earth require piles to render them sufficiently compact and solid."

Bernard F. de Bélidor (1697-1761) preferred to construct the foundations of bridges within 'encaissements,' i.e., sheet piles with king piles around the perimeter, then to remove soft material from within and fill with a mass of concrete or dry rubble stones. T. Hughes in 1843 commented that such foundations should be allowed some time in which to settle and become solid before the dressed masonry was laid in courses upon them. He added that this method shews great savings over cofferdams !

It is commonly believed that Gothic masonry was invariably sound. Nevertheless failures occurred even when the outward appearance of the stonework was honest enough ; several great towers collapsed. These and other accidents were sometimes due to the risks taken by the architects, but generally because the foundations were inadequate or the walls badly constructed. Thus at Chichester,

> " . . . . before the spire fell, the mortar of the interior ran out like water when a stone was withdrawn."

Contemporary records shew that occasionally great care was taken to carry foundations very deep. Elm piles were used under buildings at the Tower of London, Hadleigh Castle, and the Bulwark at Sandwich ; oak piles at Winchester, and alder piles at York. Iron-shod piles were employed under London Bridge and Rochester Bridge. Primitive pile-driving machinery is specifically mentioned in documents of the fourteenth to sixteenth centuries.

An example of bad foundation techniques was revealed early in this century at Winchester Cathedral. The first cathedral had been erected on marshy ground *c.* 980 A.D. with water only 10 ft. below ground level. When the second stage of building began in 1079, short oak piles—some salvaged from the first cathedral —were driven into this ground and the foundations laid on them. In the third stage of building, *c.* 1200 A.D., the new builders had to move still further into the marshy ground. Coming like their predecessors to water 10 ft. below the surface, they found themselves uncertain how to proceed. As the best they could do, they cut down a wood of beech trees, laid these flat, and on them raised a building which is " one of the gems of English art." The trouble which followed, and which nearly brought this part of the building to ruin, began as soon as it was built. The tree trunks did not decay, but were pressed down into the soft ground ; the arch vaults became disturbed and pushed out the walls, and the whole building split off from the Norman part west of it and slid eastwards, leaving gaping cracks in many places. The repairs consisted of grouting the walls and underpinning the foundations and will be referred to in more detail later.

On the other hand, repairs to the structure of St. Paul's Cathedral, London, in 1922-30, shewed that serious damage caused by settlement could not have been foreseen by Sir Christopher Wren (1632-1723) ; the damage was largely the result of subsequent disturbance of the subsoil, to which however, defects in the masonry contributed. For example, the piers at crypt level carrying over 7000 tons each are approximately 43 ft. long by 20 ft. wide, but consist only of a 12 in. thick veneer of Portland stone inside which all kinds of pieces of stone, brick and lime are to be found. All eight piers subsided to varying degrees (2 $\frac{1}{16}$ in to 6$\frac{1}{8}$ in. are mentioned) giving rise to high stresses in the masonry and causing pieces of stone to flake off from time to time. The dome of St. Paul's Cathedral was the chief structural innovation and achievement in English building between 1500 A.D. and 1700 A.D. and Wren predicted that it would last for 200 years. It is of interest to recall that during the Great Fire of London (1666) which preceded the building of the present

Cathedral (1668), the debris from the fire was spread out, thus raising the ground in Cheapside to its present level, i.e., some 18 ft. higher than in Roman times. The depth to which the foundations of the Cathedral were carried, however, was only 4 ft. 6 in. below the floor of the crypt, i.e. 12 ft. below the surface of the churchyard, whereas on the opposite side of the street the warehouses are 25 ft. deep. Furthermore, the foundations lie, not on the London clay but on the overlying waterladen sands and gravels.

When in 1831 in connexion with the proposed construction of a sewer in Godliman Street a pit was put down to a depth of 31 ft. below street level, i.e. 20 ft. below the Cathedral foundations, a serious danger to the Cathedral was created. Out of this pit 'hundreds of tons" of quicksand or silt were removed by the steam pumps used which led to protests by such famous engineers as Telford (1757-1834), M. I. Brunel (1769-1849), Rennie (1794-1874), and Cockerell (1788-1863). The sewer scheme was ultimately abandoned but the damage to the Cathedral had been done. Sir John Wolfe Barry (1836-1918) and Sir Francis Fox (1844-1927) were both consulted in connexion with the repairs at different times, and, more recently, Sir Alexander Gibb and Sir Ralph Freeman have completed the work.

About 1913 Fox received permission to sink for exploratory purposes an artesian well in the crypt. When an electric light was lowered into the well, water was seen to be flowing literally towards the River Thames some 1,000 yards away. It was necessary, therefore, to grout with cement under the Cathedral lest the water remove any more of the finer sands and silts. Cement grouting was a process much used by Fox, and as it had proved a valuable process in many other situations, Fox sought to use it at St. Paul's. Permission was received from the Cathedral authorities to try the experiment of grouting the subsoil at the west end of Cheapside. Abyssinian wells were driven down to the clay and cement grout at a pressure of 400 lb/sq. in. was injected; it is reported by Sir Francis Fox that very satisfactory results were obtained. He states that an examination was made down to blue clay, a total depth of 42 ft. below street level; water was reached at 32 ft. depth and gravel and 'quicksand' for a depth of 11 ft. He found on examination that the cement grouting had been sufficient to create a solid conglomerate of the sands and gravels and had even permeated the sandy layers in the clay. He adds that in 1922 when he examined the quicksand, there was considerable vibration due to the passage of omnibuses and heavy motor vans along the roads above.

One of the more surprising facts which has emerged during this study is that in Chicago, before 1874, the most commonly used foundation material was hard limestone, evenly bedded, and 8 in. to 20 in. thick. The slabs were called 'dimension stone,' and were used because concrete was not considered reliable. About that time Frederick Baumann (1826-1921) a Chicago Architect of German origin conceived the idea of using isolated piers for his foundations such that the pier areas were proportioned to the pier loads and the centre of pressure of the load was arranged to be central on the base. He advised limiting the ground pressure to 20 lb/sq. in. which, he said, would limit settlement on the hardpan crust to one inch during building and ½ in. during the following six months. W. L. B. Jenney recommended placing foundations on the hard crust and made borings 20 ft. deep to examine the ground conditions. In 1884-1885, timber grillages were introduced; in 1878-1882, old steel rails were used and in 1888 steel I beams formed the grillages. In 1885 to 1891 the County Building founded on short piles 30 ft. long settled 18 in. and from 1884-1929 the Board of Trade building sank 21 in. About 1895, engineers regarded a settlement of 5 in. as normal and acceptable and it is interesting to find reference to the acceptance of settlement if not to its study and understanding.

In 1908 Professor A. N. Talbot at Illinois University began his researches on the distribution of pressures under foundations. In 1915 A. L. Bell published his celebrated paper on earth pressures, but the full significance of his work was not appreciated for another 20 years. It is probably true to say that design for settlement is only now becoming recognized as the appropriate method where relative movements of the superstructure are important. Dr. G. G. Meyerhof's paper to this Institution in 1947 was a notable addition to the literature.

What then do we learn from all these facts? It seems to me that the changes which have been taking place in the course of history have been largely those associated with the development of plant and equipment. Even in the middle of the nineteenth century it was possible for Cresy to say:

> "The application of the steam engine to bridge building has wonderfully economised both labour and time; piles are driven, their heads cut off by its power; manual labour has been greatly abridged, and the use of horses almost rendered unnecessary .... and heavy weights are moved by very simple tackle and machinery."

And whereas in 1908 a hand-book on excavation methods said this:

> "The systems adopted comprise barrow runs, horse and cart, and rail transport; the latter include hand trollies, horse wagons and trucks drawn by locomotives and by ropes worked by stationary engines",

today vast quantities of mechanically operated plant are used. In the few short years during which I have been privileged to work in structural engineering (some 35 years), practically all the modern techniques have been evolved. No wonder it seems impossible to keep abreast of developments. What do we do today? We excavate, seldom by hand, often by machinery. We compact the ground by mechanical rolling or ramming, we place a layer of in-situ concrete by machinery and then we construct our reinforced concrete foundations using all kinds of mechanical aids. We take care to place the concrete as quickly as possible and with the aid of vibrators. We place the concrete as dry as possible to avoid the effects of moisture upon the ground. But the ground has not changed; largely it is our methods of construction which have improved.

For the foundations of some new flats in Eastbourne, Sussex, recently erected, it was necessary to excavate piers down to a depth of 20 ft. on to a hard layer of 'plavender' or cemented greensand; the intensity of loading was approximately 4 tons/sq. ft. and an average pier load was 100 tons. For this purpose hand excavation was used in the shallow piers and a mechanical excavator was used down to a depth of about 15 ft.

A few months earlier, in Accrington, for column bases supporting loads of about 300 tons, excavation into shale was effected by means of rotary boring equipment forming a hole about 4 ft. 6 in. diameter which was belled out to 6 ft. 6 in. diameter at the base. It may be of interest to record that the design load on the shale was taken as 12 tons/sq. ft.; some small samples of the shale obtained during a preliminary

drilling and trimmed to form blocks about 1 in. × 1 in. × 1 in. were crushed to a failure pressure of 73 tons/sq. ft.

So far as the theoretical design of foundations is concerned, it would probably be true to say that little more than the simple division of total load by safe bearing pressure as suggested by Baumann was used until relatively recently. Leonardo da Vinci (1452-1519) is said to have been first to calculate the forces in a structure, but no reference is made to foundations. The name of Robert Hooke (1635-1703) is well-known but not in relation to foundations. Some engineers or builders seem to have appreciated better than others the importance of settlement; for example, reference has been made already to T. Hughes's comment about 1840 that foundations should be allowed time in which to settle before the superstructure is built. But the concept of designing for equal settlement rather than equal bearing pressure is recent. Would it be right to say that it has only developed during the last 35 years? The publication of *Erdbaumechanik* by Terzaghi in 1925 was the starting point for independent thought on foundation design. Dr. Oscar Faber (1886-1956) (Past President) will be remembered as one who enquired into and measured distribution of stress under isolated column footings.

The references to grouting in connexion with Winchester Cathedral and St. Paul's Cathedral may serve as an introduction to a few historical notes on this and kindred subjects.

The Romans probably were aware of the value of grouting, but they had not the equipment. Cement grouting using a grout pan was patented by Mr. James H. Greathead (1844-1896) for tunnels in 1886.

In 1930, cement injection was used for consolidating the Thames gravels under the Turbine Basement of the Power House at the Ford Motor Company works at Dagenham, though with limited success on account of the high porosity of the gravels. An early reference to consolidation is that of Friedrich Hermann Poetsch of German origin, whose patent for 'freezing' the ground by chemicals was dated 1884; and this was followed in 1894 by the Jesiorsky process. Certainly by 1908 it was possible to consolidate running sand by chemical injection. The Francois process of cement injection was introduced in 1909 and the Lemaire-Dumont process in 1914. There is also a reference to freezing being used to sink a mine in South Wales in 1862.

Recent techniques for dealing with water in the ground include well-points. One of the most spectacular uses of these was in 1943 in the Surrey Commercial Docks, London, when a dock area was dewatered to permit the construction of the Mulberry harbour units used in the invasion of Europe in 1944. The yield from the wells was about 800 galls/min. when equilibrium was reached. The modern 'well-points' used in connexion with ground water lowering are said to be modifications of the Abyssinian well invented during Napier's campaign of 1868 and used by the Royal Engineers ever since.

In about 1930 Sir Henry Japp (1869-1939), who was my chief for some years, and Mr. F. E. Wentworth-Sheilds (1869-1959) (Past President) used large diameter wells with submersible pumps for dewatering the area of the new dry dock at Southampton during construction. The use of large wells had been promoted in Germany in 1927 at a depth of 72 ft. At Southampton the maximum depth was 96 ft. Today well-points in one of many forms can usually be relied upon to handle large quantities of water in difficult waterlogged foundation conditions.

Some seven years ago in 1954 well-points were used successfully to lower the ground water at one end of a site in Purley Way, Croydon, to permit the construction of a basement for a new office block. The interesting feature was the fact of handling one end of the site in contrast to the whole area.

One of the latest applications of deep wells is to be seen at Dungeness at the site of the Nuclear Power Station where the wells are about 130 ft. deep.

During World War II a method referred to as 'Electro Osmosis' was used in Germany and Norway in which the water in a soil mass is caused to flow in a predetermined direction by the application of an electric current. It might be regarded more as a method for improving the ground by reducing the water content rather than for lowering the water table. It has many promising features, however, and may be used more widely in the future; at the present time the cost seems higher than for other methods.

The work of saving Winchester Cathedral referred to earlier constituted a unique instance of the use of grouting, the technique of underpinning and the employment of a diver. It lasted from 1906 to 1911.

Before the work was commenced, Mr. T. G. Jackson, R.A., the architect, had a trial hole sunk some distance from the building and he found that, although the foundations had been carried down by the builders in 1079 A.D. and 1202 A.D. to a depth of 10 ft. below the surface, the work had been stopped at that level by water. In those days pumping was not understood, nor were the uses of caissons, compressed air and other modern appliances known to builders.

In this trial hole it was found that below the water level a bed of marley clay 6 ft. in thickness existed which rested on a peat layer 8 ft. 6 in. in depth. This in its turn was supported by a fine bed of flints.

The problem was to find the best method to be adopted for the removal of the peat and the substitution of concrete or masonry without pumping.

Sir Francis Fox was appointed to collaborate with Mr. Jackson. His experience of bad and dangerous foundations led him to the conclusion that the aid of a diver would provide the solution to the problem.

Fig. 4 may serve to illustrate the conditions. The walls of the Cathedral were first grouted by means of the 'Greathead' grouting machine to fill all the cracks.

A pit was then sunk about 5-6 ft. long and by its means the old foundations were uncovered and the beech trees exposed. Water was then reached, and with the aid of ordinary excavation and light pumping the clay was removed and the peat bed uncovered. Pumping had then to cease.

The water was allowed to rise to its normal level, and the work was continued by the diver. The peat beneath the wall over the length of 5-6 ft. was excavated.

As soon as this excavation was completed down to the gravel, jute bags filled with dry concrete ready mixed were lowered to be placed side by side until the whole area was paved over with bags. These were then slit open to allow the material to be spread over the surface.

Four such layers of bags were thus placed in position; then a sufficient length of time was allowed to elapse for the concrete to set, after which the inflow of water was checked, and the water in the hole pumped out.

The work was then continued with in-situ concrete by ordinary labour and bricklayers up to the underside of the original foundation.

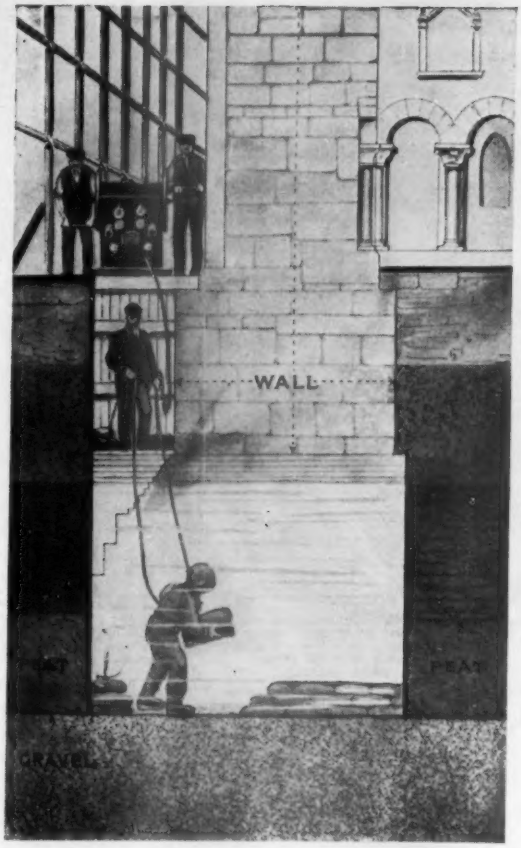

Fig. 4—Winchester Cathedral—foundation repairs

Underpinning was necessary at Peterborough Cathedral in 1845, and at Salisbury from 1859 onwards. At Peterborough there is solid limestone only a few feet below the floor, but the original foundations were not carried down to it. Many other cases of bad Romanesque architectural planning could be cited, but Romanesque foundations in England were often excellent. Bonding-timbers, carefully framed together and embedded in the masonry, were used in Norman foundations of churches at York and Lewes and in several castles.

An interesting reference to underpinning is to be found in *The Development of English Building Construction* by C. F. Innocent. Henry Chester, the chamberlain, underpinned a house in Chevelyngham; he drove thin pegs or wedges of wood between the wooden cill and the stone foundations thus giving rise to the term 'underpin.'

In 1932 the consolidation of the gravel for underpinning at Bentall's, Kingston, Surrey, was carried out by the Joosten chemical injection process in conjunction with groundwater lowering by well-points. This had been used first by Dr. H. J. Joosten in Nordhausen, Germany, in about 1925-1926.

The first application of the process in this country was in 1932 at the Bank-Monument Underground Station where the loose sandy gravel overlying the London clay was consolidated, thus permitting construction of the cast-iron tunnel lining in unsupported ground.

A modification of the Joosten process was invented about the time of World War II by Professor A. Guttman which makes the treatment applicable to fine-grained soils. Both processes are two-injection treatments in which a precipitate of silica gel is formed in the soil by the chemical reaction between a highly concentrated solution of sodium silicate and a strong salt solution usually calcium chloride. The chemical consolidation is effective in sea-water.

During the past thirty years or so, the author has been connected with many schemes involving underpinning. In 1942, a reinforced concrete framed building in the East End of London, supporting a water tank on the roof, was damaged by enemy action which largely removed the supports to the water tank as well as puncturing the tank itself. This building also contained one of the factory boiler houses. Accordingly after repairing the tank, a steel framework was erected inside the building up to the floor of the water tank and at the top of this frame stub cantilevers were arranged in such a way that, by tightening the anchor bolts, the cantilevers were caused to lift the water tank structure and thus relieve the main reinforced concrete columns of their loads. It was then possible to cut out the defective reinforced concrete, reconstruct the columns and floors and finally to reapply the water tank loads to the columns. During the work the tank, which contained some 100,000 gallons of water, was kept full for fire-fighting and other purposes. This same building was also modified at a later stage to enable it to house additional boilers, and for this purpose one wall at ground level was removed and replaced by a reinforced concrete framework. This entailed underpinning the wall and for this purpose the wall was carried temporarily on needles jacked up from a temporary steel framework. By adopting a jacking method it is possible, and indeed it is necessary always to impress into the temporary and the permanent works all the deflexions likely to be involved so that when the loads are transferred finally to the new structure, no further deflexions may take place.

Some five years ago, the King's Head Hotel at Darlington was extensively modernised and for this the whole of the ground floor was 'gutted' and a new steel framework inserted. Jacks were used extensively. One of the old columns which was a cast-iron column of cruciform section supporting about 200 tons had to have its lower length removed, so that it could be re-supported on a new system of beams. Fig. 5 shews the arrangement and also shews that to transfer the load from the cast-iron column to the new steel beam the cast-iron column was surrounded by a steel box and encased in concrete. The concrete served to transfer the load to the box and then to the temporary steelwork which was carried on temporary timber shores jacked up to support the column positively. The lower length of column was then burned away and the new steel beams inserted and deflected by further jacking and finally the old column was lowered on to the new steelwork.

When Grosvenor House was extended some five or six years ago, it became necessary to support the existing column foundations whilst a new deeper basement was constructed. For this purpose a series of bored piles was driven around the site, nearly touching next to existing bases and open spaced elsewhere. The piles were thus arranged to carry the vertical loads of the new columns and at the same time to retain the ground and prevent settlement of the existing bases. Fig. 6 is a photograph of the arrangement.

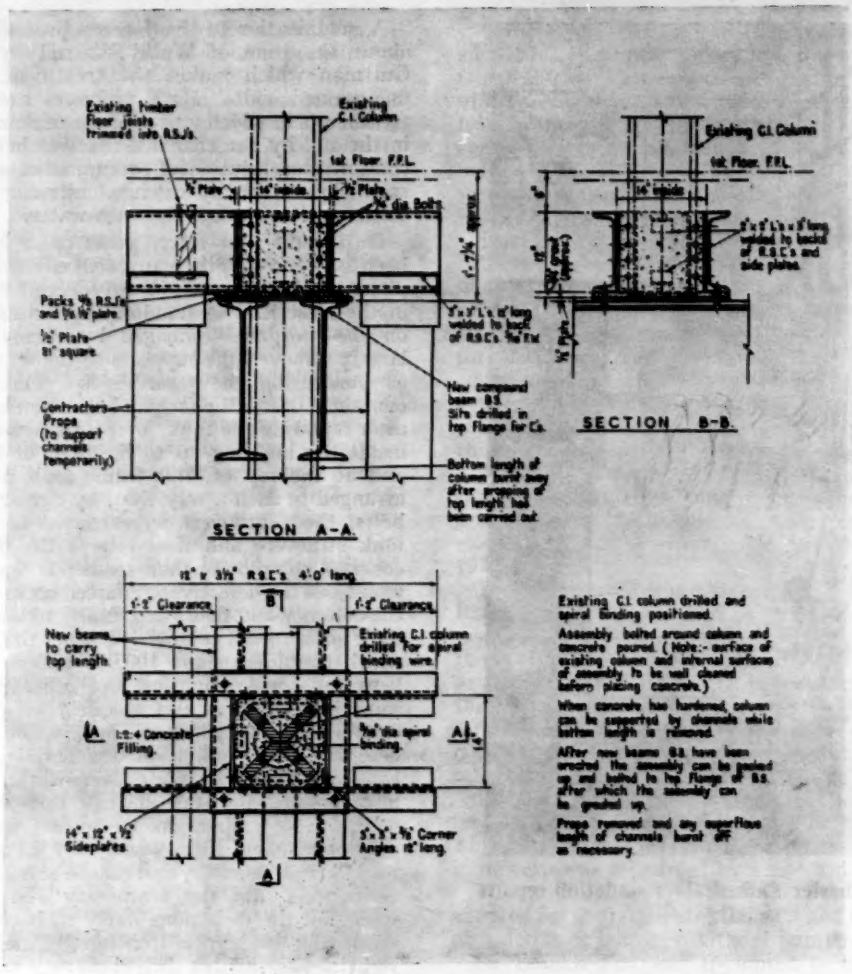
Existing Timber Floor joists trimmed into R.S.J's.
Existing C.I. Column
1st Floor F.F.L.
Packs ⅜ R.S.J's and ⅜ M.S. plate
½" Plate 21" square
Contractors Props (to support channels temporarily)
New compound beam B.S. Slits drilled in top flange for Cs.
Bottom length of column burnt away after propping of top length has been carried out.
SECTION A-A.
Existing C.I. Column
1st Floor F.F.L.
SECTION B-B.
12" x 3⅜" R.S.C's 4'-0" long
1'-2" Clearance
B
1'-2" Clearance
New beams to carry top length
Existing C.I. column drilled for spiral binding wire
1:2:4 Concrete Filling.
¾" dia spiral binding.
14" x 12" x ½" Sideplates
3" x 3" x ⅜" Corner Angles 12" long.
Existing C.I. column drilled and spiral binding positioned.
Assembly bolted around column and concrete poured. (Note:- surface of existing column and internal surfaces of assembly to be well cleaned before placing concrete.)
When concrete has hardened, column can be supported by channels while bottom length is removed.
After new beams B.S. have been erected the assembly can be packed up and bolted to top flange of B.S. after which the assembly can be grouted up.
Props removed and any superflous length of channels burnt off as necessary.

Fig. 5—King's Head Hotel, Darlington—alteration of cast-iron column

During the rebuilding of Binns store in Middlesbrough, the adjoining buildings required underpinning to permit the new basement to be constructed at appreciably lower levels. For this purpose, rows of bored piles were constructed alongside the existing buildings and to depths sufficient to enable the piles to support both vertical loads and horizontal ground pressures. The existing building walls were then cut away in short lengths and reinforced concrete stubs built into them off the tops of the bored piles. By this means, the loads on the walls were transferred to the bored piles in stages. It was then possible to excavate on the new site to calculated depths at which temporary timber strutting was introduced to resist the horizontal reactions in the piles.

Fig. 7 shews the underpinning of a block of flats known as Milbrooke Court, Putney, during reconstruction of the foundations following war damage caused by a bomb falling through a wing of the building. Particular attention is drawn to the extensive use of jacks, the object being always first to lift the building to be carried and, secondly, to deflect the new work to such an extent that when the loads are imposed, the new work will not deflect further and cause cracking. The method has proved very successful and has prevented the subsequent development of cracks.

Reference has been made in discussing the work at Winchester Cathedral to the fact that compressed air techniques were not known in 1200 A.D. There is a brief reference to compressed air by a John Taisner of Hainault in 1509 and the use of compressed air for underwater work seems to have been suggested by Coulomb (1736-1806) in 1779.

Compressed air, however, was first used by John Smeaton in 1778 when repairing the foundations of the Hexham Bridge over the Tyne. In 1841 or thereabouts the French mining engineer M. Triger developed a method for sinking shafts which enabled men to work with the water excluded. In 1843, an English medical doctor, Lawrence H. Potts, (1789-1850) obtained a patent for a foundation method by which cast-iron cylinders fitted with a top lid were lowered with the aid of atmospheric air pressure. This was achieved by momentarily reducing the air pressure under the lid by connecting it to a vacuum pump and allowing the external air pressure to press the cylinder into the soil. The method was used for several bridges in Britain, diameters of 10 ft. and depths of 100 ft. being on record.

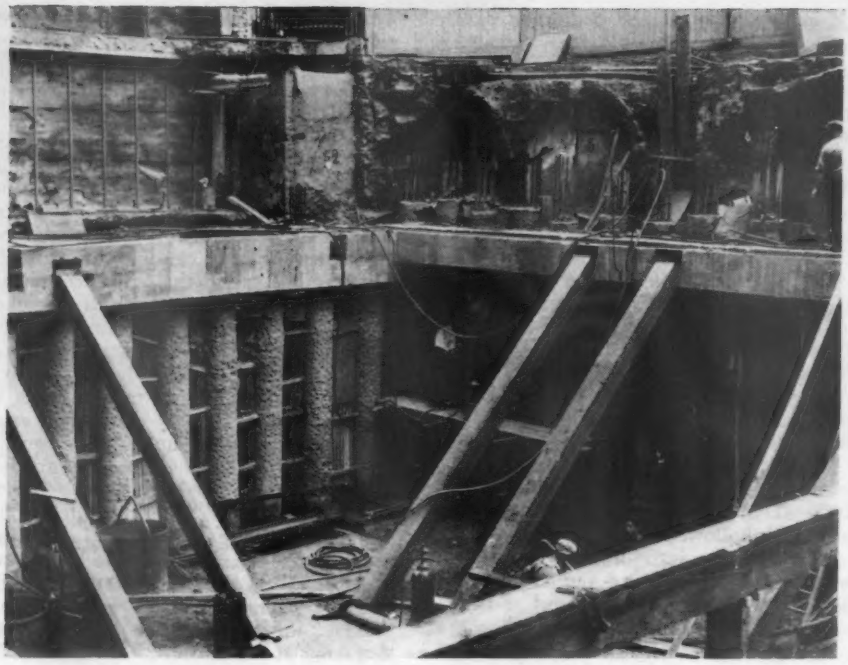

Fig. 6—Grosvenor House, Park Lane—elevation of piles

Because of difficult foundation conditions at Rochester Railway bridge in 1850, and to enable the men to descend to the bed of the river to level the site of each cylinder, Potts's method was not suitable and the piles used were made to perform the duty of diving bells. Whilst reference is made by Aristotle to a diving bell used by Alexander the Great at the siege of Tyre in 332 B.C., and a number of similar contraptions are referred to in subsequent years, e.g., Lorena 1531, the forerunner of the modern diving bell is undoubtedly the apparatus designed and contructed by Dr. Edmund Halley (1656-1742) in 1690. The original diving bell contrived by Halley was improved by Smeaton and this in turn was entirely superseded by Mr. John Hughes's (1807-1874) application for foundations in deep water. Compressed air was made to free a cast-iron hollow pile from the water within it after it had been placed in position on the bed of the river and the bell was left to form part of the permanent structure. Such a scheme is mentioned by Dr. Ure as having been that used on the banks of the River Loire by M. Triger in sinking shafts through quicksand 65 ft. thick to a stratum of coal. It seems that it was usual to drive such cylinders into the ground by a dropping weight.

There is an amusing reference to a diving bell in connexion with the building of the seaport of Canopus in about 1900 B.C. A sea nymph is credited with recommending " a glass vessel large enough to contain several draftsmen with a supply of materials and food " ; it was to be lowered to the bottom of the sea so that the draftsmen could sketch the marine monsters supposed to be responsible for tearing down the works. A bell and rope for the men inside to indicate when they wished to ascend was also suggested.

Fig. 7—Millbrooke Court—underpinning

John Hughes's method marked the beginning of a new epoch in foundation engineering. I. K. Brunel (1806-1859) used the method on the Chepstow and Saltash bridges (*c.* 1850). These tubular foundations were the forerunners of the 'modern' caisson foundations, the first of which was used for the construction of the Rhine Bridge at Kehl in 1859. Today caissons are used widely either with or without compressed air according to the ground conditions. Indeed caissons have developed into large rectangular shaped structures, sometimes called monoliths. The largest known to the author was the steel and concrete caisson of the circulating water system at the Usk Power Station, Monmouthshire, which measured 164 ft. by 110 ft. in plan and was 80 ft. deep. The maximum weight was 42,000 tons and the caisson was provided with six air-locks. Those at the Howrah Bridge were 181 ft. 6 in. long and 81 ft. 6 in. wide, whilst a recent example at Aberthaw Power Station was 95 ft. in diameter.

A variety of caisson seems to have been used in Egypt about 2000 B.C. Such caissons were made either of timber or of hollowed-out stone and were sunk through conglomerate into limestone to an overall depth of 66 ft. The hollowed out stone was placed in a shallow pit, excavation carried out and the wall built on to the caisson as it sank.

The first use of caissons in recent years without compressed air seems to have been by the Swiss architect Charles Paul Dangeau de Labelye (1705-1781) who designed Westminster Bridge in 1738. The first use of monoliths or rectangular caissons seems obscure, but there is a record of an open well caisson (or monolith) being used in Holland in 1908.

It may be of interest to recall that the term 'caisson' is the French form of an Italian word. 'Cassa' is a chest or case and the addition of the syllable 'on' means 'a large chest.'

The first application known to the author of a caisson or cylinder to the foundation of a structure was made in about 1930 when the Princes Street Branch of the National Provincial Bank was being constructed. Heavy concentrated column loads combined with poor ground conditions due to the proximity of the Walbrook stream led Sir Henry Japp to suggest the use of cylinders for certain of the column foundations.

The first use of compressed air in tunnelling was covered by a patent in 1830 by Sir Thomas Cochrane: it was used in a small way in 1839 in France for a pit shaft. Compressed air tunnelling seems to have been used in Antwerp in 1879, in New York in 1879 and on the London and Southwark subway in 1886.

Whilst it is not proposed to include in this survey detailed reference to retaining walls, the following comment by Sir Benjamin Baker (1840-1907) is worth repeating since it helps to remind us that all our work has limitations imposed by the assumptions we make.

Baker in 1881 summed up his views on retaining walls as follows:—

> "Something must be assumed in any event, and it is far more simple and direct to assume at once the thickness of the wall than to derive the latter from equations based upon a number of uncertain assumptions as to the bearing power of the foundations, the resistance to gliding and other elements. The numerous published Tables giving the required thicknesses of retaining walls to three places of decimals stand really on exactly the same scientific basis, and have the same practical value, as the weather forecasts for the year in Old Moore's Almanack."

On the other hand, Terzaghi in 1936 commented:

> "The fundamental misconception associated with the traditional earth pressure computation does not reside in the theory as such. It lies in the failure of designers to consider the limitation of the validity of the theoretical results."

Admittedly, theory has advanced, practice is better understood and even weather forecasting is now based on greatly enlarged scientific information; nevertheless, we need repeatedly to remind ourselves that in the realm of foundation engineering no theoretical answer can be closer to the truth than the original assumptions are to the actual conditions. Foundation engineering is both an Art and a Science.

One of the most interesting aspects of foundation engineering is the examination of the ground prior to carrying out the work. Whereas to-day there are many techniques possible, in former days much ingenuity had to be used. For instance, in Roman times, after a site was determined upon, wells were sunk to try the nature of the soil: if fit to bear the weight of the construction intended to be put upon it, they commenced their foundations for the outer walls, which were always based upon a 'solid' stratum. This would seem to be the first reference to a site investigation.

After the fall of the first tower of Ely Cathedral in 1321, it seems that the site investigation, such as it was, for the new tower took place as follows under the direction of the mason in charge. He

> "measured out in eight divisions the place where he thought to build the new tower; and he set workmen to dig and search for the foundations of the eight stone columns whereupon the whole building should be supported until at last he found solid and secure ground. Then, when these eight places had been carefully dug out and firmly founded with stones and sand, at last he began those eight columns."

Little of a positive nature is known of the methods of site investigation until more recent times but there is no doubt that some builders were aware of the need for ascertaining the ground conditions. In particular, the bridge builders seem to have appreciated the dangers of founding their bridges upon unknown ground, and there are several references to prodding the ground with an iron bar.

Thomas Telford (1757-1834) was an engineer who understood the importance and made use of ground exploration prior to preparing his designs. Before designing the Caledonian Canal he wrote to John Richman in 1804:

> "....the nature of the soil and the quality of the material having now been sufficiently proved for the purpose of determining the...."

Similarly, Telford sank boreholes to obtain information for his bridge foundations as he recorded for the eastern abutment of the Gloucester Bridge (1825). Apparently he used there an auger which unfortunately struck a stone during boring. The foundations were constructed in cofferdams using piles of 30-32 ft. long with a space of 5 ft. between filled with puddled clay. The foundations comprised a bottom course of flat-bedded rubble, two layers of Memel logs, 4 in. beech planks and then the masonry.

Writing in 1843, John Weale says:

> "In his practice as an engineer Telford was exceedingly cautious and never allowed any but his most experienced and confidential assistants to have anything to do with exploring the foundation of a building he was about to erect. This scrutiny into the qualifications of those employed about the foundations extended to the subordinate overseer, and even to the workmen, insomuch that men whose general habits had before passed unnoticed, and whose characters had never been inquired into, did not escape Telford's observation when set to work in operations connected with the

> foundations. He was accustomed to examine men so employed whom he thought unsteady .... It is evident from these precautions that Telford was well convinced how dangerous it was even to receive a report of the strata from men of careless habits or inefficient knowledge, and that he also knew the consequences which might follow from careless pile-driving and from the absence of proper care in all the operations connected with the commencement of an important structure."

In 1828, Robert Stevenson (1772-1850) of Edinburgh, describing in his Specification the Hutcheson Bridge to be built across the Clyde at Glasgow, referred to its having been ascertained by boring and mining that the subsoils of the bed of the river consisted of gravel, sand and mud.

In 1842, William Hosking, F.S.A.(1800-1861) stated that the various substances of which the ground is composed and the thickness vertically of each substance, could be obtained by boring with a species of auger made for the purpose.

> " A long pointed iron rod may be used with advantage in the preliminary examination of the ground and of the bed of a river .... The comparative ease or difficulty with which any rod may be forced down into a sound bed of clay .... will enable an observer to judge with tolerable accuracy .... before the process of boring is undertaken."

By 1856, we read that sounding the soil to ascertain its nature was done by an iron rod driven in by a pile engine, or

> " by an auger that will bring up the soil as in sinking an artesian well."

At that date, soundings were known to have been taken to a depth of 80 ft. by using a strong chest made of planks, about 18 in square, the bottom of which was shod with iron. M. Fauvelle (*c.* 1856), of Perpignan, France, described an easy method of boring to any depth, either for examining the soil or for obtaining water.

> " If through a hollow boring rod water be sent down with the bore-hole as it is sunk, the water in coming up again must bring with it all the drilled particles."

A bore 560 ft. deep, 6 in. diameter is said to have been made at Perpignan in 140 hours about 1850.

In connexion with the building of Rochester Bridge (*c.* 1850) reference is made to the fact that the bed of the river was found, by boring, to consist of strata of soft clay, sand and gravel overlying the chalk, which appeared at a depth of 44 ft. below the average high water line.

In 1882, when the swing-bridge over the Dee at Chester was under consideration, a boring was put down over 100 ft. revealing nothing more solid than quicksand on which to base the bridge. When, during the construction, the main cylinder lurched over, a 2 in. iron pipe with nozzle was used to provide a water jet to correct the cylinder.

By 1880, trial borings for proving strata were being carried out more regularly by Le Grand. There is a record of a boring at Silvertown in May 1903 for the London County Council; at St. James Square in November 1904 for the Hammersmith to Bow Railway and at Euston in September 1905 for the Underground Electric Railways Co.

One writer comments that until modern methods of site investigation were developed—from about 1920—elaborate specifications of foundation work expressed 'a hope rather than a promise.'

And it was not until about 1930 that undisturbed cores began to be taken. Le Grand, Sutcliffe & Gell in *Bulletin No.* 13, September 1939, shew a drawing of a coring tool designed by Mr. T. P. Le Grand which is very similar to the present standard tool. The cores were waxed and sealed in tin canisters and sent to the Building Research Station for testing. It might not be unfair to say that the Science of Soil Mechanics was officially recognized at the First International Conference on Soil Mechanics and Foundation Engineering held at Harvard University in 1936. The object of that Conference was to collect and to co-ordinate information which at that date had been obtained by engineers and soil scientists all over the world.

Today, the importance of adequate site investigation cannot be exaggerated. And yet, in some quarters still, the cost is looked upon as scarcely necessary, a possible time waster and certainly not a means for economising. Even in 1935, A. C. Dean advised that a site investigation, including test piles, undisturbed samples and the soil strata sequence should be carried out on all sites of important works. Recent experiences have emphasized how essential it is to explore the ground fully before embarking on the design of important or, indeed, any foundations.

When examining the ground for a bridge some two years ago, it was found that the chalk varied markedly from one end of the bridge foundation to the other end; in a distance of 120 ft. the safe ground pressure varied from 1½ to 6 tons/sq. ft. It is reported that Sir Robert Smirke (1781-1867) the architect of the early 19th century, when preparing the foundations of the General Post Office at St. Martins-le-Grand stated that he had to cover the whole site " where a greater diversity of subsoil was never before exposed to view."

The so-called uniform London clay has been found to contain wide variations in its quality, and often down to depths of 70 ft. it has been found to have been disturbed. Some months ago when boring piles in London clay 110 ft. deep, a nautilus was found in one pile at a depth of 60 ft. and a piece of pyritised wood in another pile at a depth of 90 ft.

By reason of their similarity to boreholes, etc., it may not be out of place here to refer very briefly to artesian wells.

Artesian wells have been known in Italy, Austria, Crimea, Siberia, Sahara, Palmyra, Tyre and Egypt for many years. Their name stems from their use in Artois (Latin name Artesium), France.

Whilst some form of well drilling has been practised in China and India for about 2000 years, probably the oldest well in existence is that at the ancient convent of Chartreux which is dated 1126. There is mention by Belvoir of one in 1749 at the monastery of St. André near Aise. In 1833, an artesian well sunk at Grenelle in Paris passed through a depth of 1,798 ft. and took from 30th November 1833 to February 1844, costing 303,000 francs. Artesian wells were introduced into London in 1794 at Norland House, Kensington. Other early wells in this country were sunk at Sheerness and at Fulham in 1824. It seems from the records of Le Grand Adsco Ltd. that they commenced constructing tube wells by percussion methods in about 1872. Their oldest record is of a well so completed at Eltham, Kent in 1874; prior to that, wells were mainly dug.

It may be worth putting on record that from 1937 " Electrical Resistivity Surveys " are reported as having been used commercially in site investigations of a special character, particularly those connected with large dams and marine works.

In his discussion on the use of timber, Vitruvius says that the alder, which grows next to the banks of rivers and seems a useless timber, has nevertheless some remarkable applications.

> "And so frequently alder stakes, being fixed in marshy ground below the foundations of buildings, admit fluid because they have less quantity in their substance. Hence they remain imperishable to eternity, uphold immense weights of walling and preserve them without decaying. Thus a timber which cannot endure even a short time above ground, when it is buried in moisture abides for long periods."

It is of interest in this connexion to reflect that the Boucherie process of timber preservation was used in France in 1767; that Mr. H. P. Burt was honoured in 1853 by the Institution of Civil Engineers for his pioneer work on Timber Preservation and that in 1884, Mr. S. B. Boulton read a paper to that Institution on "The Antiseptic Treatment of Timber."

Vitruvius goes on to refer to buildings at Ravenna, both public and private, all of which were supported on piles. Thus it seems that piles are at least 2,000 years old (and maybe more). He says also:

> "the spaces between the columns are to be arched over, or made solid by being rammed down, so that the columns may be held apart. But if a solid foundation is not found, and the site is loose earth right down, or marshy, then it is to be excavated and cleared and re-made with piles of alder or of olive or charred oak, and the piles are to be driven close together by machinery, and the intervals between are to be filled with charcoal. Then the foundations are to be filled with very solid structures. The foundations being built to a level, the stylobates are to be laid."

It is recorded that the Pontus Subilicus, a wooden bridge, was constructed about 500 B.C. in the reign of Ancus Marcius. 'Subilica' means a pile, which suggests that the bridge was built on piles. The bridge is mentioned as that which was defended so valiantly by Horatius Cocles.

Thus might well begin some remarks upon the history of piles and piling. Unfortunately it has not been possible to discover much information about the machinery used in those far-off days for driving the piles: but that piles were used seems beyond question

Proceeding down the years, references to piles, apart from planks, are numerous. In 1239 beech trees were given to the Franciscans at Winchester to make piles for the foundations of their buildings. At York in 1327 alders were brought

> "to make piles for the foundations (fundis) of the cellar underneath the Queen's private chamber and of the cellar below the new chapel and also for the foundation of the latrine."

So also, nine elms were bought "for piles for the foundation of the postern" at the Tower in 1348, and 20 elms "for piles whereof to make the foundation of the King's chamber" at Hadleigh Castle in 1363; while at Sandwich in 1470 a payment of 10s. 8d. is recorded.

> "to Morice White and his felawys a great (i.e. a contract) to dryve pyles in the fundacon of the Bulwerk."

Piles were naturally required for the making of such works as wharves and weirs. Thus in 1360 at Gravesend 128 pieces of elm timber were bought "to make piles thereof for the new wharf." When a contract was made in 1432 for the construction of a wharf at Norwich the mason was

> "to take the ground pile it and plank it with englysh oke of hert or ebel (i.e. poplar) of a reasonable thickness .... and thereupon begynne the seyd kaye of freston,"

the part behind the stone facing being filled and rammed with marl and gravel. A similar backing is implied in the accounts for Berkhamstead in 1386, when a man was employed to dig clay "for ramming the wharf of the new mill at the sides," eight bundles of moss being at the same time supplied 'pro wharfo stuffando.'

At York in 1365 straw had been used to bind the soil, when men were employed some six weeks repairing the bay (caput) of the Fosse stream and

> "beating and ramming (attribant' et tupant') the earth and mud, strengthened with straw, with rammers (tuppis) and great hammers."

In the accounts for repairing a weir at Nottingham in 1318 we find eight men driving piles and

> "three carpenters sharpening piles and making bowetrys and shorys and setting them upon the weir."

More elaborate details are given in 1400 when a sluice was remade in Windsor Park. William atte Hethe, 'pondemaker,' was paid £6 9s. 10d. for piling and ramming 50 ft. by 40 ft. of the 'netherbay' of the sluice. A list is given of the timbers required for making the said 'sklus' and a great bridge over it; namely 20 'grundeplates' each 30 ft. long, 65 pieces called 'nedylls,' four 'bembes' (beams); and for the bridge six posts, 16 braces, three someres, four 'entertayes,' 120 'gistes,' two rails; and at the head of the said 'sklus' a grate of three postes, three braces, 30 'moynells,' with a bridge over the same; also a flodegate of eight postes, eight braces, six flodegates, and a bridge over it; and 7,000 ft. of boards, three inches in thickness.

In the construction of bridges piles often practically constitute the foundation. Thus when old Rochester bridge, built 1383-93, was removed, it was found that about 10,000 piles had been employed in making its piers. They were of elm, 20 ft. in length, the starling being constructed of half-piles driven in close together, filled with chalk, and covered on the side and top with elm planks; on top of these an 8 in. platform of Kentish ragstone formed a foundation for the masonry of the bridge. Such piles were shod with iron; two 'pylschoun,' weighing between them 100 lb., were supplied for Rochester bridge in 1407, and John Smyth of Chatham supplied another 28, totalling 402 lb., in 1438. These are exceptionally heavy; eight shoes of iron used for piles at Calais in 1441 only weighed 27 lb., and the 100 irons for piles mentioned in the stores of material belonging to London Bridge in 1350 were valued at 4d. each, which corresponds to a weight of about 3 lb.

The inventory just quoted also mentions two engines, or machines, with three 'rammes' for ramming the piles of the bridge. Some contrivance of this kind had been in use from very early times; in fact it would hardly have been possible to drive piles without it. In form the ram, or pile-driver, consisted of an apparatus in the nature of sheer-legs, carrying a pulley by means of which a heavy block of wood or iron, the 'ram' proper, could be hoisted and let fall on the head of the pile. There is reference, in an account of 1256 for Woodstock, to a carpenter making 'sliddreies' and 'rammes,' of which the first term can only be guessed at, but may mean the uprights between which the ram slid. The ram occurs in a latinised form of its French equivalent, mouton, at Westminster in 1289; "pro j truncco ad j multonem inde faciendum," the price paid, 12d., showing that it was a very large log. There is a further entry of the provision of a 'haspe cum apparatu'—some sort of fastening with its fittings—for the mouton. In 1324 men were 'driving' piles in the foundations with a great engine called 'ram' at the Tower, where also we find 6d. spent "pro iij bideux pro le ram" in 1348. An inventory of stores at Westminster in 1387 mentions "a ramme with all fittings." At Calais "a gynne called Ram, used for fixing piles" occurs in 1468; "a machine called a Fallyng Ramme" is found in 1473 at Sherne,

and a gynne with a Rammer of brasse was borrowed from the Wardens of London Bridge for work at Westminster in 1532.

In the Rochester bridge accounts for 1457-8, we find 18 men employed in working the ram for fixing piles, each working for 58½ tides, at 3d. the tide. Probably work would be possible for about three hours on each side of low tide, but whether they were all working continuously together or, as seems more probable, in shifts, does not appear. Further entries show 2 lb., of tallow bought for greasing the great 'hauser,' and 6d. paid for tarring (terrying) it. The work was not without occasional incidents to relieve the monotony, if we may judge from an entry in 1409-10. That year 10 'tydemen' were paid at the same rate "for driving (pur chacer) piles during 12 tides, and two others for helping during one tide; of which one tide was on Sunday after vespers, a great tempest of wind and rain, and eight men fell into the water and were nearly drowned, wherefor they had extra, as a gift, in firing, bread, verjuice (veriiose) and wise, 22d."

A more usual plan was to drive in piles and Horman in 1519 says:

> "a quavery or maris and unstable foundations must be holpe with a great pylys of alder, rammed downe, and with a frame of tymbre called a crossaundre."

Such a method was known in very early times and was used, for instance, by the Romans when building the walls of Anderida (now Pevensey) on the edge of the marsh. For work on the port at Sandwich in 1463 we find not only 50 elms provided for piles and slabbing (platis) for the foundation of the bridge, but in this second example the slabs were probably not laid on the soil to give a firmer foundation but were nailed to the piles to form the starlings.

It would seem therefore that the primary purpose of piles in early times was to compact or consolidate the ground; the idea of using piles solely for bearing vertical loads appears not to have occurred to the architects and engineers of those days. Indeed, when Edward Cresy wrote his encyclopaedia in 1861 he stated somewhat categorically that the object of pile driving was to consolidate the ground: he added, however,

> "that piles are also resorted to when a solid stratum lies at a depth too great to uncover or when it is crossed by layers of soft earth difficult to remove."

He advised:

> "that bearing piles should be loaded with a weight equal to the load to be carried and that such weight should be left on a sufficient length of time to remove any doubts upon the subject."

> "The only means of judging correctly," wrote Cresy, "the resistance of a pile is to examine the nature of the stratum on which it bears, the hold which it takes and whether it has penetrated a solid not susceptible of yielding under the weight of the construction such as rock or gravel, provided this latter cannot be washed away with the current. The refusal of a pile to advance does not always ensure its having arrived at a proper bed, the nature and consistency of which should always be previously ascertained."

Many instances could be adduced where piles have sunk under the weight placed upon them for want of these considerations. For the piled foundations of bridges, Alberti specified a width of piling equal to twice the width of the wall carried. The length of the piles should not be less than one-eighth of the height of the wall to be carried and their diameter not less than one twelfth of their length. Jean Rodolphe Perronet (1708-1794) thought that 12 in. piles should not be loaded with more than 50 tons and 9 in. diameter piles with more than 25 tons.

Perronet further suggested that piles should be driven until the penetration, during the last 'heat' of 25-30 blows, does not exceed 1-2 'Paris lines' (1 line = $\frac{1}{12}$ in.) or six lines in the case of less loaded piles. "'The driving force' of the rammer," he said, "is proportional to the height of its fall," but, he goes on "On n'ignore pas combien il est difficile . . . d'établir mathématiquement aucun rapport entre les forces mortes (static forces) et les forces vives (dynamic forces)." In Perronet's pile engine, the essential features were the leaders, the hammer and the multi-tailed rope. For obvious reasons it was known as a Ringing Engine. When the ram or monkey had been hauled to an appropriate height it was released by 'nippers,' a device like a pair of tongs which opened at the lower end by having the upper ends closed together. Perronet used his engine in many forms, including one driven by horse-power and one arranged on a floating craft and operated by an armed wheel.

Another famous piling engineer was Louis Alexandre De Cessart (1719-1806). For the foundation of the bridge at Saumur in 1756, De Cessart used a 10 in. diameter axis with hand wheel 12 ft. diameter; eight men turned the wheel and raised at three turns a ram weighing 1,500 lb. 6 ft. high. To regulate the height of fall and the price of driving, it was determined that it should be limited to a stroke of 8-10 ft.: the price was 20s. per pile including transport: the scaffold piles cost 10s. each. In all these machines, however, the hammer weights were generally not greater than one ton and usually much less. By 1861 it seems that De Cessart had also invented a machine for withdrawing piles and one for cutting the heads under water. By 1861 a steam pile driver also had been invented and was in use in America. A steam hammer evolved from an idea of James Nasmyth (1808-1890) was used for pile driving at Devonport in 1845.

It may be of interest to record that when in 1902 the piles under the Campanile of St. Mark's, Venice, were examined, although they were 1,000 years old they were found to be good enough to support the new building.

And in 1919 the rock elm piles used under the Newcastle High Level Bridge and driven in 1846 were still in good condition.

The technique of using a 'jumper' for cutting through a hard layer seems to have been well known by 1861. Cresy says that holes may be pierced with an iron-shod piece of timber or rod of iron working perpendicularly through a frame or hole cut in a large stone.

The method of driving piles with the aid of a water jet was used for driving the piles to support the scaffolding for the Severn Railway Bridge in 1875 and was attributed to Sir James Brunlees (1816-1892) who had used a similar technique at the Kent and Leven Viaduct in 1856-57. This device was of especial value in the Severn valley where the bed of the river consisted of "28 ft. of tenacious sand" overlying the old red sandstone. There is also a reference to jetting having been used at Matagorda Bay in 1852, the idea of Geo. B. McClellan of U.S.A. Corps of Engineers.

The use of long piles under buildings particularly seems to have developed, at least in Chicago, in the years 1883-1890. Their introduction however gave rise to much litigation on account of the effects of the pile-driving on nearby structures. At that time cast-iron caps were used on the piles and drop hammers were 2,800, 3,200 or 3,800 lb. weight each. The height of fall was as much as 35 to 40 ft. and the movement of the pile was of the order of 3 in. per blow. It is recorded that during the driving of piles at the Illinois Central

Station, some piles already driven were observed to rise 4 in. In 1893 an improved technique of pile-driving was used on the foundations of the Chicago Public Library; a Vulcan steam hammer with a weight of 4,500 lb. and a drop of 42 in. working at 54 blows per minute was employed. A set of 48-64 blows per ft. for a normal pile or 24-32 blows per ft. if a 'follower' or 'dolly' were used was specified. The design load was 30 tons per pile and a group of four piles was tested to a load of 50·7 tons per pile.

At this time there seems to have been little known about calculating the bearing capacity of a pile. About 1820 A. J. Weisbach (1806-1871) published a formula based on alleged fundamental energy considerations which also included a term to account for the elasticity of the hammer: in 1851 the Journal of the Franklin Institute contained a formula put forward by a Major John Sanders of the United States Corps of Engineers for timber piles driven into river mud. It took the form $R = WH \div 8S$ R being the *safe* resistance; this formula is interesting in view of Perronet's opinion some 75 years earlier that the driving force is proportional to the height of fall of the hammer. In 1862 W. J. M. Rankine (1820-1872) published his formula which seems to have been based upon the theory of elastic impact developed by a Dr. Whewell (1794-1866) in 1841. Its form is complex and was simplified in 1929 by Mr. G. B. R. Pimm (Past President).

Pimm's form of the Rankine formula is comparable to the formula published in 1888 by A. M. Wellington (1847-1895) in America and often known as the 'Engineering News' Formula. It is used with a factor of safety of six on the assumption that no pre-exploration of the sub-strata has been made, i.e. no site investigation has taken place. The values assigned to the constant it contains are as varied as their authors; accordingly for any particular site a calibration may be carried out to fix the particular value. If account be taken of the effect at impact of the relative weight of the pile and the hammer, then the Wellington formula assumes the form of the Dutch formula often used with a factor of safety of six.

There are other similar variations and it might not be an unfair comment to say that the variations depend largely upon the authors' personal views of the relative importance of the terms they include or reject. Eytelwein (1764-1848) gave a form almost identical with the Weisbach-Dutch form.

It thus seems that from the middle of the nineteenth century much activity occurred in an attempt to evaluate a fair relationship between the bearing capacity of a pile and the measurements which may be taken during the final stages of driving. Since those days there have been further attempts of a somewhat 'hit and miss' character and it was not until 1925 that a serious attempt was made to put the matter upon a reasonable basis. In that year there appeared in *Engineering* a rational pile-driving formula published under the name of A. Hiley (Member) which claimed to be applicable to most ordinary methods of driving piles. Hiley's final conclusions appeared in *The Structural Engineer* in 1930; a factor of safety of three or four was recommended. The derivation was from the original basic considerations which had produced the Weisbach, Wellington, and other similar formulae so that its value consisted largely of the tables published by its author and assembled from a wide range of piling practice. The Hiley formula has enjoyed wide popularity, particularly in this country; the Wellington formula has continued to be used abroad, particularly in America. Nothing should be said to minimise the value of Mr. Hiley's contribution to the subject of piling formulae for it is fair to say that with the advent of his formula, most other formulae went out of use, and much loose thinking was eliminated.

Nevertheless, it has some limitations. For example, the calculated resistance to driving for a particular pile varies widely according to the weight of the hammer used or the hammer drop allowed; it also seems to exaggerate the importance of the weight of the pile. Consequently, there appeared in 1947 under the name of Dr. Oscar Faber (Past President) a 'New Piling Formula.'

This formula might fairly be said to be 'empirical' in nature. A certain factor p in the denominator was called by Dr. Faber a plasticity factor; when driving in non-cohesive or granular materials, $p = 1$, but when the toe of the pile rests in a substantially cohesive material, the resistance to driving was found by Dr. Faber to be greater at the time of driving than some hours after. On the other hand, for driving in cohesive material, Dr. Faber added a quantity to account for the 'take-up' which occurs with time. Thus 1947 saw built into a dynamic formula for the first time two important factors, namely, the plastic or viscous property of the ground at the toe and the adhesive or friction property of the ground surrounding the pile.

Dr. Faber's formula has not received the recognition which it deserves, for in the view of the author it represents an advance on Hiley's formula. On the other hand, the present writer has found cause to criticise it and ventured, therefore, in 1959 to suggest another method for calculating the bearing capacity of driven piles. Here the suggestion is made that the toe support and the side support can be separately calculated whether the pile is in cohesive or granular material and added to give the total support. The toe value is based upon the mathematical work of Isaacs and Fox first published in 1932, which considered the force at the toe of the pile as set up by a longitudinal wave motion passing down the pile. The form of the relationship is simply $T = R + F$ where R is the bearing capacity at the toe and F is the value of the friction on the walls of the pile. The value of R is subject to a plasticity factor when the toe is driven into a plastic material and the value of F can be positive or negative according to whether the friction supports or 'drags down' the pile. Whilst it would be immodest to claim much for this latest effort the writer has found it to give results which account for much of the 'scatter' usually associated with such calculations. It might be emphasized also that this value of R is the resistance to penetration under a *static* load and not the resistance to driving as previous formulae have given.

It is of interest, therefore, to reflect that although the technique of driving piles into the ground has been used, if not understood, for perhaps two thousand years, it is only in the last 100 years or so that a quantitative approach has been made. There are those to-day who say that a dynamic approach should not be made; rather, they assert a static calculation is the more reliable, depending as it does upon the properties of the ground and not upon the technique by which the pile is placed therein. Perhaps, after all, Sir Benjamin Baker was not so far wrong when he said:

> "by no amount of sticking in of pins could it reasonably be expected to consolidate a pat of butter."

A. C. Dean suggested, even in 1935, that remoulding of the clay occurs when piles are driven into it. And in 1856 Cresy wrote:

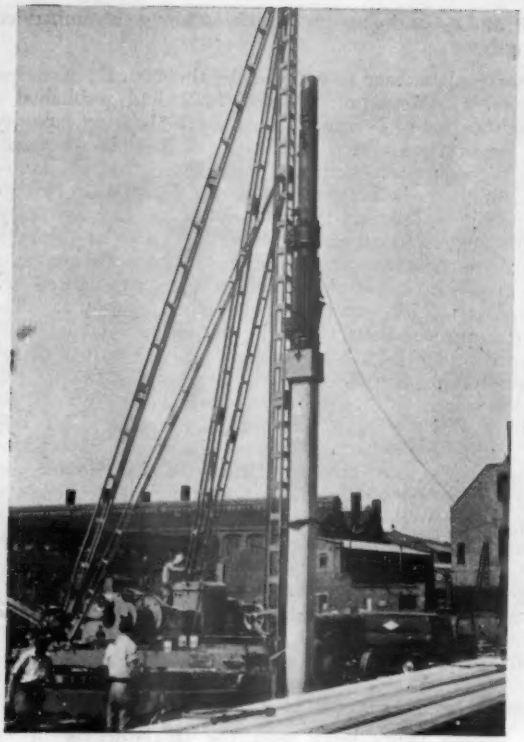

Fig. 8—Delmag Hammer

"in clay, naturally firm, the pile sometimes becomes a conductor to the water which insinuates itself along the sides, softening and producing a settling, which would not have taken place had piling not been introduced."

It remains a fact, however, that some satisfaction is obtained when it is known that the 'driving is hard,' so that there must be some merit in endeavouring to compute the value of the 'hard.' This endeavour is illustrated by the fact that one book enumerates about 33 dynamic formulae as well as eight static and six empirical.

Until the end of the nineteenth century, most piles seem to have been made of timber. Precast reinforced concrete bearing piles were introduced by Edmund Coignet (1850-1915) in 1894 and by Francois Hennébique (1843-1921) in 1897. Reinforced concrete sheet piles were used in Morocco in 1916-1918 and in this country at Wisbech in 1929, and at Stratford, London, in 1928-29.

An outstanding development in the driving of preformed piles is the Diesel hammer, a machine produced in Germany and capable of revolutionising pile driving. Fig. 8 shews the medium size hammer in use on a contract in West Ham driving 14 in. × 14 in. reinforced concrete piles. The driving characteristics of this equipment are such that the blow is fully transmitted to the pile and the pile moves so smoothly that similar piles have recently been driven alongside a brickwork wall supported on strip footings at ground level. A warning should be sounded as to the output of energy per blow: according to detailed measurements made by the writer, the published energy figures are realized only when driving is hard enough to cause the piston to rise to its full height. When the driving is softer, the piston does not rise high enough to allow the hammer to deliver a full blow, and under such conditions it is necessary to adjust the calculations. It has been found possible, however, to apply the writer's new calculations to this form of hammer.

In contrast to timber or precast piles, there have been developed those piles which are placed in the ground rather than driven in. There are however certain intermediate forms of piling in which a tube is first driven into the ground by one method or another, and later filled with sand or concrete. For example, the earliest of these appear to have been :—

Sand Piles The use of sand piles for foundation support in poor ground was common from about 1830-1850. Structures in Bayonne and elsewhere on well rammed sand piles are referred to. Gauzence is credited as requiring the sand filling to be moistened and rammed 'until his walking stick could not be pushed in.'

The Raymond Pile The original pile was continuously tapered and was used in America about 1897. The maximum length used was under 40 ft. It was subsequently introduced into this country in about 1931 and then gave place to the step-tapered pile which can be driven in lengths up to 80 ft.

Simplex Piles These were brought into this country in 1905 from America where they had been in use for some years. They were introduced here by H. P. Lancaster, a Founder Member of this Institution; the first contract was in 1906 at Birkenhead.

The Franki Pile This system of piling was invented Mr. Edgard Frankignoul in 1909; the first trials were made in Liège in 1909 and the first foundations built were for the new offices of the Division Calcinage de la Société Anonyme John Cockerill. In 1925 the then four varieties of piles were replaced by the present method of driving a concrete plug within a steel tube and this method has been used all over the world. The standard hammer weighs about two tons and the tube varies in diameter from 14½ in. to 24 in.

Vibro This system was first used in 1920 or thereabouts and consists essentially of vibrating wet concrete into a hole formed by a steel tube. It was invented by Mr. A. Hiley and described by him in March 1927; 689 such piles were used for the rebuilding of St. James's Park Station.

Prestcore This system was first used in 1930 or thereabouts and was introduced to overcome the danger inherent in placing wet concrete into water-laden ground. Short lengths of precast concrete are threaded into a tube and later grouted solid as the tube is withdrawn.

West's Shell pile was developed in several stages between 1923 and 1934 by Mr. Alexander Rotinoff (Member) a Russian engineer of British nationality; the first shell piles were driven in 1929. In 1934 the patent rights were taken over by the present Company and the form modified to that which is used to-day. It consists of precast concrete tube shells threaded on to a steel mandrel assembled on a concrete shoe. The whole unit is driven into the ground although the greater proportion of the hammer blow is applied to the mandrel and thus to the toe. The mandrel is then withdrawn leaving the hollow pile in the ground, and this is filled with concrete and a reinforcement cage as necessary.

The Holmpress Pile This was introduced some twenty-five years ago; it consists essentially of a steel shell driven into the ground which is later filled with concrete. The outer tube is withdrawn at the same time as the wet concrete inside is driven into the ground by another hammer of smaller diameter. This form was introduced as being preferable to a simple bored pile with expanded base which had been used by the same firm for some few years previously (*c.*1930).

All these forms and a number of others of recent introduction are driven in some measure first and then cast in-situ.

To-day there are those forms of piles in which no driving occurs, but in which a hole is bored or augered in the ground, and the hole is subsequently filled with concrete. The earliest of these seems to have been :—

The Smith's Pile The first bored piles were put down in August 1919 in interesting circumstances. The firm, an old-established company of well drilling contractors, was approached in 1919 by a Grimsby architect, Mr. Walsh, who was faced with a foundation problem when building a new cinema. It was not possible to drive piles owing to the effects on adjoining buildings and Smith's were asked if they could bore holes down to boulder clay, put in a cage of reinforcement and fill with concrete. Thus the first fifty 12 in. diameter bored piles were installed and the load-carrying capacity was assessed as 20 tons per pile. The Expanded Pile Co. Ltd., was formed in 1947. A belling tool for under-cutting the bases in cohesive soils was patented in 1935. In 1957 the firm constructed their first large diameter rotary bored piles, namely eighty piles 36 in. diameter 70 ft. deep with mechanically cut bases 7 ft. 6 in. diameter.

Pressure Piles These were evolved first in Germany in early 1920 from standard well-boring equipment, and were introduced into this country in 1928 by Mr. J. F. Barr. The first piles used were in the foundations of the Custom House at Belfast and the Playhouse, Edinburgh. One of the original features of this pile was the provision of an air-lock on the tube to facilitate placing the concrete when the tube and ground were waterlogged. To-day this is little used, other methods being employed to combat the effects of water.

These and many other bored piles are now available, in varying diameters suited to the ground condition.

So far as the question of calculating the bearing values of in-situ type piles is concerned, there have been many static formulae put forward. In a Treatise on Civil Engineering in 1895 W. R. Patton stated that $T = AB + SF$ for buried piers and gave in tabular form values for B and F according to ground conditions. Patton applied Rankine's theory of earth pressure making use of various measured values of $\varnothing$ (the angle of internal friction in a granular material) and μ (the coefficient of friction between various materials). Bénabencq in 1911 gave a carefully detailed formula making due acknowledgement to the works of Rankine, Falmant and Résal. 1922 saw the Dorr formula, 1927 the Vierendeel formula and 1932 an essentially empirical formula by Wilcoxen based on model tests. A distinct advance was made in 1954 when Golder and Leonard published the results of some researches on piles bored into London clay. These gave results equivalent to $T = R + F$ where $R = 9.c_p.A$ and $F = 0{\cdot}7.c_a.1.4d$ where c_p = the cohesion of the clay at the toe of the pile and c_a = the average cohesion along the embedded length.

This result seemed to confirm the theoretical researches of G. G. Meyerhof who in 1952 had published a modification of Terzaghi's work on the bearing capacity of foundations. More recently still in 1959, Professor A. W. Skempton, F.R.S. has suggested that the factor 0·7 ought to be between 0·3 and 0·6 say, 0·45, with a limiting value of 2,000 lb/sq. ft. in London clay, (also suggested earlier by Meyerhof). One of the most important factors in these calculations is the value of the cohesion of the clay which is usually measured in a triaxial machine on an 'undisturbed' sample. The term appears, however, to be somewhat relative, since Ward and others have shewn that the values of the cohesion measured on hand-cut samples taken from excavations (in tunnel) are often nearly twice those obtained by normal sampling methods. This may account for the differences between Skempton's coefficients and those put forward by Golder and Leonard. The present author's experience tends to suggest that the coefficient $N_c = 9$ at the toe seems to rise to perhaps 12 and the adhesion coefficient to fall more nearly to 0·3. Once again, the differences may be due to the measured values of the cohesion depending upon the tests used and the method of preparation of the samples. On some tests carried out at Audley Square, London, W.1, on bored piles 24 in. diameter 110 ft. long, there is little doubt that the coefficients were nearer 12 and 0·2 respectively.

Recent years have seen the introduction of the modern cylinder or caisson pile, with or without an enlarged base. In 1924 Mr. Rotinoff obtained a German Patent for what he called 'a sectional caisson pile' of one metre diameter and in 1930 this form was introduced. About 30 years ago a technique was introduced by Benoto for sinking cylinders one metre diameter by the combined operation of grabbing inside and oscillating outside a cylinder placed in the ground. This process in a variety of forms is operated to-day by a number of British contractors and constitutes an efficient means of excavating to considerable depths, 100 ft. and more, to construct a vertical cylinder of concrete. A development of this has been introduced from America (the Chicago caisson pile which was really a well and was under-reamed by hand was introduced in 1894) for piles in clays whereby the excavation is removed by an augering process, and in which it is possible at a specified depth to 'under-ream' to produce an enlarged base. Such an arrangement has enabled very large loads to be carried on single columns in cohesive ground although it is by no means certain that the settlements attending such high concentrations of load are properly understood. Whilst it might be considered a cynicism to remark that such piles have been as instrumental in promoting argument as in solving foundation problems, it is true that the relative amounts of support achieved by the toe and the sides of the pile are constantly under discussion and many rather 'immature' statements have been made from time to time. The matter is the subject of much research at the present time; contractors have been able to find common ground and working with Consulting Engineers have set up a research committee, which includes the Building Research Station, to carry out a number of full scale tests. In the past, little recognition has been given to the supporting value of the friction on the sides, but there seems to be developing a view that the skin friction is more important than the toe resistance. The forerunner of these cylindrical supports was clearly

Fig. 9—Audley Square—general view

the caisson foundation used and described by Vitruvius 2,000 years ago ; Vitruvius wrote :

> "Then, in the place selected, dams are formed in the water, of oaken piles tied together with chain pieces which are driven firmly into the bottom. Between the ranges of piles, below the level of the water, the bed is dug out and levelled, and the work carried up with stones and mortar, compounded as above directed (viz. hydraulic lime and pozzuolana mortar) till the wall fills the vacant space of the dam."

In 1842 Hosking referred to the use of caissons for bridge piers and suggested the desirability of pre-loading a foundation to ensure that it settles fully before the first load is applied. This in 1842 indicated a considerable appreciation of the inevitability of settlement as well as of its importance and might well serve as a useful piece of advice to us to-day.

One of the most recent foundation techniques to be introduced is called Vibroflotation. It is a technique applied to fine sandy material of low density whereby the material is subjected to vibration to increase the density and thus the bearing capacity. It has been used in America, West Africa and North-West England and is at present being applied on the North-East coast.

A recent and very successful application of bored piling has taken place at a site in Mayfair, W.1. The site which is shewn in Fig. 9 is to be occupied by a multi-storey garage building and lies between existing buildings of some age, perhaps 200 years. The foundations of these buildings are near the ground surface, and on one side the buildings are some 90 ft. high and the foundations are loaded to about 14 tons/ft. run. In order to excavate to depths of as much as 25 ft. below these footings, it was decided to install around the perimeter of the site and as close as possible to the adjoining buildings cast-in-situ bored piles. These, generally, were 17 in. diameter but to carry heavy column loads occurring at intervals 24 in. diameter cast-in-situ piles were installed amongst the 17 in. piles. The large piles were designed to support 120 tons each and, on account of the disturbed quality of the London clay at this site, the piles had to be 110 ft. long. The normal triaxial tests applied to samples of the clay shewed that the clay had been disturbed at some time in its history and relatively low values were measured. Reinforced concrete walings were cast against all these piles as excavation proceeded, and the walings and piles were then strutted apart by using precast reinforced concrete struts. The struts were loaded positively to pre-determined calculated forces by the insertion of ' flat ' hydraulic jacks as shewn in Fig. 10. By these means, the forces on the struts could always be kept large enough to prevent any movement of the ground outside the bored piles thus preventing any settlement of the adjoining buildings.

It may be of some interest to add a brief note on screw piles. Screw piles were invented by Mr. Alexander Mitchell (1807-1848) and were widely used by him and others for the foundations of lighthouses, beacons, piers, jetties and breakwaters in situations where soil was composed of loose and unstable sand, or when the waves might undermine the work. In 1851 at the Goodwin sands, a hollow pile 6 in. diameter was screwed down easily to more than 50 ft. through fine and compact sand. It seems that about that time no device was as successful as inserting into the sand a bar of iron having at its lower end a broad plate or disc of metal, either of spiral or helical form, like a screw. The area of the plate was determined upon after the stratum it was to enter had been examined by boring : in a few cases, a diameter of 4 ft. was used.

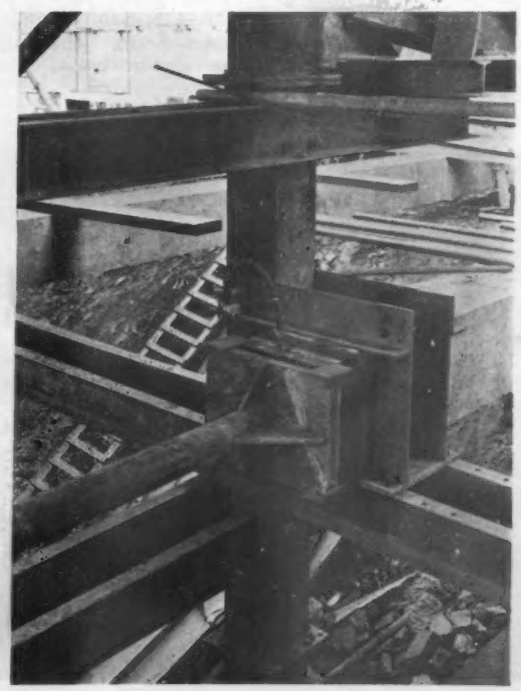

Fig. 10—Audley Square—hydraulic jack

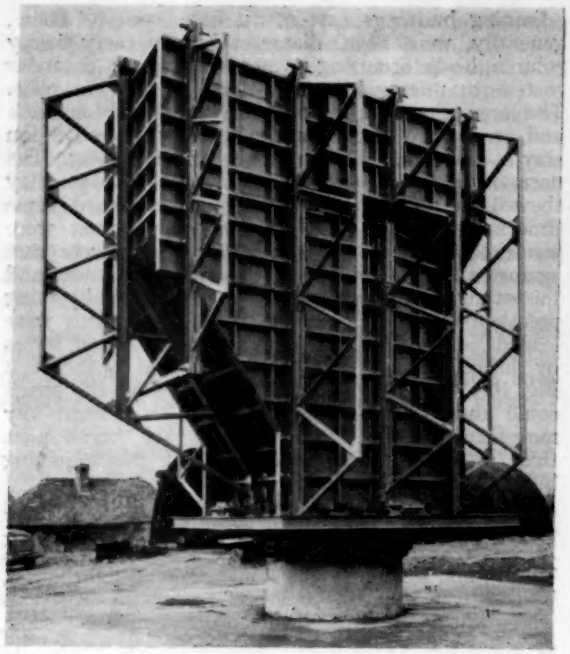

Fig. 11—Stelmo shuttering to precast cylindrical pier

One of the earliest structures (1838) thus supported was the lighthouse on the Maplin sands : these piles were 5 in. diameter 26 ft. long, with 4 ft. diameter blades. Eight piles were used at the corner of an octagon. Disc piles were used in 1856-7 by Sir John Brunlees on the Kent and Leven viaduct and they were driven with the assistance of water jets.

For the existing swing bridge at Caernarvon, all the river supports are on cast-iron screw piles 6 in. diameter about 30 ft. long, with 4 ft. 6 in. diameter blades and when they were examined some years ago they were found to be in excellent condition and quite capable of supporting a proposed new bridge.

Fig. 12—Modern American house on cylindrical pier

Fig. 13—Ancient pagoda on cylindrical pier

To-day screw piles in various forms are available, some in metal, some in reinforced concrete ; and piles with more than one blade have been introduced in recent years where the ground conditions have been particularly soft.

A brief reference to sheet piling may be appropriate. Telford conceded to Thomas Farnolls Pitchard the credit for introducing cast-iron into bridge construction about 1775. The first use of cast-iron for sheet piling appears to have been in the early 19th century at Bridlington Harbour. In 1822, a patent was taken out by Peter Ewart (1767-1842) a pupil of Rennie and in 1832 a patent using wrought iron was claimed. Cast-iron sheet piles were used at Brunswick Wharf, East India Docks in 1834. At the end of the 19th century, Larssen in 1897 used steel piles at Bremen. To-day there are many varieties. One of the earliest uses of the 'Universal' section was to form the cofferdams at the Western Entrance of the Royal Albert Docks, London, in 1932 when the entrance gates and locks were being reconstructed.

Thus must be concluded a few rather superficial remarks upon various aspects of Foundation Engineering. One of the fascinating results to the author has been to discover that although engineering is as old as man, significant progress has been made only during the last 100 years or so ; it may even be claimed that many of today's methods are as recent as 35 years old.

The following three figures are a commentary perhaps upon the matter.

Fig. 11 shews the steel shuttering for casting the deck brackets on the tops of precast prestressed cylinders on a new jetty in the River Tees.

Fig. 12 shews a modern American house supported upon a cylindrical pile.

Fig. 13 shews an ancient pagoda constructed in Hanoi, probably 2,000 years old and supported upon a single cylindrical pile.

Is any further comment necessary?

When this address was first under consideration it seemed possible that it might form the subject of a detailed discussion of the development of engineering equipment. The information available, however, has been found to be so vast that many cuts nave had to be made and many matters of great interest omitted. The author has regretted that this has been necessary, but even so the printed address is much longer than he would have wished.

He would hope, however, that the information offered may prove of sufficient interest to encourage others to write more fully on specific subjects and thus to widen and deepen our knowledge of this subject which, coming within the sphere of the Structural Engineer, may ensure that he is 'Always on a sure foundation.'

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Book Reviews

Statik der Pfahlwerke (Statics of Piled Structures), by F. Schiel, (Berlin/Göttingen/Heidelberg: Springer Verlag, 1960) 9¼ × 6¼ in. in., 148 plus viii pp., D.M. 28.50.

In this book on the statics of piled structures a general theory of design is presented based on recent research and, in particular, on the work of Asplund, and this is adapted for use in special cases. The author has not thought it necessary to deal with the soil mechanics side of the subject since this is well covered elsewhere, and thus the so called "floating" foundations are not considered. Advanced mathematics are not used in the development of the theory.

Beulwerte ausgesteifter Rechteckplatten (**Buckling Coefficients of Stiffened Rectangular Plates**) by Kurt Klöppel and Joachim Scheer. (Berlin: Wilhelm Ernst & Sohn, 1960). 12 in × 9 in., Introduction, 45 pp. + diagrams, 107 pp., tables, 2 pp. 48 D.M.

In contrast to the British Code of Practice on the Use of Structural Steel in Building (B.S. 449: 1959), which in Clause 28 gives rules of thumb for the provision of web stiffeners, the German Code DIN 4114 requires the proof of adequate safety of the web against buckling. This is an extremely complicated mathematical problem necessitating a vast amount of numerical calculations that can only be done by computing machines. The present book provides tables and diagrams for various sizes of plates with various arrangements of the stiffeners subjected to bending and an axial force, shear and a combination of these forces. The basic assumptions of the calculations and the method of arriving at the results by trial and error and iteration are explained in the introduction, which also contains five examples to show how to use the tables and diagrams. A description of the mathematical tools used in the computations would be far beyond the scope of a review; suffice it to say that the practical application of the results in any given case is comparatively easy. It would be well worth while to check the rules in Clause 28 of B.S. 449: 1959, on the basis of the very comprehensive material contained in this excellent book.

K. H-K.

Theory of Elastic Stability, 2nd Edition, by S. P. Timoshenko and J. M. Gere. (New York and London: McGraw-Hill, 1961) 9 in. × 6 in., 541 plus xvi pp., 116s. 6d.

The first edition of this book was published in 1936 to serve as an introduction to the subject of stability of structures, the emphasis being on fundamental theory rather than on specific applications. It assumes a preliminary knowledge of mathematics and strength of materials and the general theory of elastic stability. In this second edition, which is largely re-written, the subject matter has been brought up to date while the presentation is mainly as before.

The Chemical and Physical Effects of Aggressive Substances on Concrete*

by P. E. Halstead, B.Sc., Ph.D., F.R.I.C.

Synopsis

The paper describes how the basic structure of concrete can be damaged. Concrete hardens by a crystallisation process and is destroyed by chemicals which dissolve the crystals and physical phenomena which disrupt them.

Commercial cements are alkaline and concrete is attacked by acids or substances like soft water, esters and alcohols which dissolve lime. Concrete is also weakened by exposure to liquors containing magnesium or ammonium ions, which replace calcium ions.

Expansive reactions occurring in concrete destroy it and examples are: delayed hydration of lime and magnesia (unsoundness), formation of calcium sulphoaluminate by reaction with sulphates from external sources, and the rusting of embedded steel reinforcement.

Temperature changes damage concrete by causing differential movement, initially by drying shrinkage and later by thermal expansion. Exposure to temperatures above 300°C. weakens all concrete by destruction of the cementive matrix but at higher temperatures aluminous cement concrete develops a ceramic bond to make refractory concrete.

Concrete is permanently damaged by mechanical overloads but has good fatigue resistance.

Intense gamma-ray and neutron fluxes may weaken the bond of concrete but in practice damage is chiefly caused by heat generated by absorption of the radiation or neutrons.

" . . . ruin and decay, it cannot be avoided but by this "
RICHARD III.

When a structural engineer is offered materials for his designs he is entitled to expect that these materials shall be stable and durable and preserve their original properties for the lifetime of a structure. Concrete meets these basic requirements generally very well but although it is a comparatively unreactive material its physical and chemical constitution is such that in certain circumstances it is vulnerable to attack by aggressive agents. Any aggressive attack impairs the useful properties of concrete and attack on a concrete structure may reduce its life and endanger its stability. In the worst cases the attack may be so severe that it threatens to cause the collapse of the structure.

It would be easy to provide a catalogue of known aggressive agents and to describe their effects on concrete but it seemed more useful to treat this topic on a more fundamental basis and examine in detail the ways in which the stability and durability of hardened concrete can be adversely affected.

It is hoped that an analysis of this kind will be more useful to structural engineers, particularly when they must decide the defensive measures necessary in circumstances where previous practical experience gives little guidance.

In order to understand how aggressive action can take place, it is convenient first to consider how the desirable properties of concrete develop.

The unique advantage of hydraulic cements is their ability to change, after the addition of water but without further treatment, from a plastic paste with no rigidity into a tough, hard material of high strength, apparently as durable as natural stone.

This is very unusual behaviour and the problem of why cements cement presents an intellectual challenge which has engaged the attention of physicists and chemists for at least a century. There is still no satisfactory explanation of the cementing mechanism available and although a great deal is now known about the hydration of cements and constitution of hardened cement paste, the reasons why it coheres are still a matter for speculation.

The physical structure of a hardened cement paste is essentially crystalline and the rigidity and tensile strength develop through crystal growth and intergrowth. This kind of phenomenon is responsible for the strength of a cube of sugar and for the setting of plaster of paris but in these examples the strength developed is only a small fraction of that attainable in hydraulic cement pastes. Other cementing mechanisms are known, such as the shrinking of a non-crystalline jelly as in bone glue and flour and water pastes, or the development of three-dimensional links between adjacent molecules to form a coherent mass as in the hardening of many plastic materials.

The action of aggressive substances must therefore cause a breakdown of the crystalline matrix which performs the hydraulic bonding in hardened concrete. This is true of all kinds of concrete irrespective of the variety of cement used, although the crystals responsible for the bonding will naturally differ according to the cement employed. For convenience, the *chemical* action of aggressive substances will be deemed to be dissolution of the crystalline matrix by reaction involving some component of it and *physical* aggression rupture of the linkages which hold the crystals together. In addition to breakdown on a molecular scale there are grosser forms of physical destruction in which forces are developed which rend structures apart by exceeding the strength of the unattacked concrete matrix. Frequently, both chemical and physical attacks take place concurrently.

The varieties of hydraulic cement which are used in substantial quantities can be considered conveniently in four groups:

1. Portland type cements: Cements in which the main hydraulic component is one or more anhydrous calcium silicates e.g. ordinary, rapid hardening, sulphate-resisting, white and coloured and low heat portland cements. In addition to proprietary variants such as waterproofed and air entraining cements, this category embraces also hydraulic limes, 'Roman' and 'natural' cements and the portland blast furnace cements of low slag content made in Great Britain.

* *Paper to be read before the Institution of Structural Engineers at 11, Upper Belgrave Street, London, S.W.1, on Thursday, 14th December, 1961, at 6 p.m.*

2. Lime-slag cements: Cements in which the hydraulic properties develop principally from the reaction of blast furnace slag with water in the presence of calcium hydroxide. These include the portland blast furnace cements of high slag content and the range of lime slag cements manufactured particularly on the Continent.
3. Gypsum-slag cements: Cements in which the hydraulic properties derive from the reaction of blast furnace slag with sulphate ions in the presence of calcium hydroxide. These are commonly called supersulphated cements and are usually composed of blast furnace slag, gypsum and portland cement.
4. High alumina cements: Cements developing a hydraulic bond through the reaction of anhydrous calcium aluminates e.g. aluminous cement and ciment fondu.

Chemical Attack

With the portland cements the bonding action is almost certainly due to the intergrowth of a crystalline mass of calcium silicate hydrate. The exact formula of this material is not known and it may not have an invariable composition. The possibility of a composition apparently freely variable within limits is not difficult to explain because although there may be an ideal formula for a single crystal unit, in concrete the crystals are not isolated and excess water and lime probably become attached to their surface. When cement pastes set or concrete hardens what probably happens is that crystal growth takes place producing sheets or foils[1] which become entangled and thereby perhaps bond together.

Sometimes the process of hardening of portland cements is assisted by heat treatment, usually referred to as steam curing if the processing temperature is below 100°C. and as autoclaving if carried out under pressure above this temperature. Treatment of this kind modifies the crystallisation processes and generally produces a matrix more resistant to aggressive substances but the general character of the material produced in this way is not substantially different in kind from that of concrete cured at normal atmospheric temperatures.

The calcium silicate bonding material is highly alkaline and is therefore susceptible to chemical attack by acids. It is even attacked by water, especially soft water containing few calcium ions, because the lime portion is comparatively soluble and tends to be leached out, leaving a loosely compacted silica skeleton. This erosion occurs in practice wherever concrete is exposed to soft raw water, as for example in dams and waterworks handling moor water, but the process is fortunately slow as long as there is no pressure tending to force the water through the concrete. One reason for the slow surface erosion is that the crystalline mass is interwoven in such a way that although lime is readily removed from the outer layers the silica which remains provides a barrier through which further lime from the interior only diffuses very slowly.

Another reason for the slowness of the attack by water is perhaps that the cement in the surface of concrete will, if exposed to the atmosphere, soon become converted superficially to calcium carbonate by reacting with carbon dioxide in the atmosphere. In industrial areas it is also likely that some calcium sulphate is formed by reaction with sulphur oxides from flue gases. Both calcium carbonate and calcium sulphate are not very soluble in water and probably form a layer on the surface of weathered concrete which resists water erosion.

The development of a hydraulic bond through inter growth of calcium silicate hydrate crystals is also very likely the essential mechanism in the hardening of lime-slag cements but other oxides, such as alumina and iron oxides from the slag, may take part in crystal growth and modify the structure. In a number of tests some portland blast furnace cements have proved more resistant to the attack of sulphates and sea water than ordinary portland cements. This seems to be associated with their lower lime content which perhaps gives a less alkaline matrix, less soluble, and less reactive.

Gypsum-slag cements differ from lime-slag cements in that the cementing action is due to the formation of a compound, calcium sulphoaluminate, essentially similar to the natural mineral, ettringite. This substance is only stable in alkaline media but, curiously, the gypsum-slag cement bond is apparently more resistant to acid attack than the calcium silicate bond of portland cement. As a result of this, concrete made with gypsum-slag cements can withstand mildly acid conditions in which concrete made with other cements would rapidly be destroyed. In spite of this good resistance to acids when it has hardened, gypsum-slag cement is vulnerable to the attack of a very weak acid, carbonic acid, when in the hardening phase. For this reason, to obtain a good hard surface on gypsum-slag cement products, it is essential to keep the surface moist and alkaline during the initial curing period. Similarly, if this type of cement is allowed to become airset, the cementive action is slow to develop because of the reduction in available free alkali.

High alumina cement is quite different from the preceding types in that the cementive bond is formed by calcium aluminate hydrate. This, like the calcium silicate hydrate of portland cements, is alkaline, but is somewhat more resistant to attack by acids[2].

There is, however, a special difference between this cement and all others in that the cementive calcium aluminate hydrates which crystallise initially are unstable and tend to change to a more stable compound of different composition and different crystal structure. Since strength and bond are dependent on crystal growth they are adversely affected by this change in form.

Experimental evidence suggests that the change takes place very slowly at normal atmospheric temperatures but it becomes significantly rapid above 30°C. Because water is involved in the hydrate conversion, moist conditions are conducive to the change and high alumina cement concrete cannot be regarded as having stable properties as a constructional material if it is exposed to warm moist conditions. The loss of strength resulting from the crystal inversion is not normally catastrophic[3] but one would prefer not to use high alumina cement for, say, prestressed beams in a laundry or cooling tower, or even for a jetty in tropical waters.

To summarise: Soft natural waters are mildly aggressive to all cements but portland and lime-slag cements are more susceptible than high alumina and gypsum-slag cements. Portland cement possesses no resistance to acids, high alumina cement slight resistance to weak acids, and gypsum-slag cements fair resistance to dilute strong acids, especially sulphuric acid.

Since all the cements are alkaline, it is not to be expected that alkalis will be aggressive but caustic soda and potassium hydroxide attack high alumina cement, presumably by dissolving the alumina portion. Portland cement seems to be unaffected by alkalis. The effect of alkalis on gypsum-slag cements does not

appear to have received much attention but it is unlikely to be serious.

Other vigorous chemical agents which might be aggressive are oxidising and reducing substances. All cements are burned in oxidising conditions so that oxidising agents do not affect them. They are also very stable towards reducing agents at normal temperatures.

Aggressive chemical attack on concrete caused indirectly by bacterial action is occasionally experienced, particularly in sewers. Sulphate reducing bacteria can generate hydrogen sulphide which is weakly acidic and will react with concrete to produce calcium sulphide. Sulphur oxidising bacteria can generate sulphuric acid at a concentration capable of destroying all types of concrete in a matter of a few months[4].

Concrete is rarely attacked by chemicals in the gaseous phase but when potentially corrosive volatile components in a gas stream are condensed on the surface of concrete attack is possible. Perhaps the commonest example of this phenomenon is experienced in concrete chimneys. When flue gases cool to the dew-point for deposition of sulphuric acid, severe attack of the concrete occurs in the deposition zone.

There remain for consideration only the chemical reagents which are not corrosive towards most building materials but have a special affinity for cements. Solutions of magnesium and ammonium salts react in this way by exchanging magnesium and ammonium ions for calcium ions. Calcium silicates become converted to magnesia and silica or to magnesium silicates[5] which are not cementive. This magnesium exchange takes place when concrete is exposed to sea water and is one of the mechanisms whereby sea water attacks concrete. Ammonium salts react with calcium silicate to produce ammonia, which volatilises leaving the calcium salt corresponding to the ammonium salt. High alumina cement seems more resistant to these types of exchange attack than portland and slag cements.

Lime is soluble in certain types of alcohol which behave chemically like acids and form calcium derivatives. Ethylene glycol, glycerol and sugar syrup are substances of this kind and they remove lime from concrete and weaken it.

The organic chemicals known as esters are composed of an acid and an alcohol and although they are neutral they can be decomposed by alkalis to their constituents. This class of substance includes solvents such as ethyl acetate, plasticisers such as butyl phthalate, vegetable and animal oils and fats and some of the synthetic aircraft turbine lubricants. All these act aggressively towards concrete and although their effect varies with the viscosity and the nature of the acid and alcohol fragments, many of them are very destructive. Portland cement concrete is least resistant, concrete made with high alumina cement or gypsum-slag cements has rather better resistance to these substances. Apart from the examples quoted above, there do not appear to be any other important classes of aggressive substances which attack all types of concrete. There are, however, destructive processes which are due to minor constituents of cements and which are different for each different cement.

Of minor importance is unsoundness caused by hard burned lime and magnesia in portland cements. Both lime and magnesia, when heated to high temperatures become difficult to dissolve in water and if present in a normal concrete mix will not have reacted very much with the mixing water before the concrete has hardened. If they subsequently react with water the bulk of the reaction product is greater than that of the original oxide and the pressure so generated can disrupt concrete. Such unsoundness is more commonly due to the presence of hard burned lime than magnesia, but in some countries great care has to be taken to ensure that magnesia does not appear in the free state in the finished cement as the mineral periclase. Unsoundness is rare in modern cements but was commoner when older manufacturing processes were in use when, in order to permit hard burned lime to slake, i.e. hydrate, old specifications would require cement to be spread out for a while in thin layers. During the slaking process heat was given off and this is perhaps responsible for the prejudice against using hot cement which still exists. Today cement is only hot because it has never had a chance to cool after having been ground.

The caustic alkalis in cements form at most a few per cent of the whole and the total sodium oxide and potassium oxide content in portland cement is frequently less than 1 per cent. This amount might normally be regarded as insignificant but unfortunately the alkalis can in certain circumstances act catalytically to destroy concrete and produce destructive effects out of all proportion to their content in the cement. The well known expansive alkali-aggregate reaction which occurs with a few aggregates found in the U.S.A., Denmark and Australia can cause complete disruption of the most massive structures and the only safeguard when such aggregates must be used is to employ with them cements of very low alkali content. This destructive reaction fortunately does not seem to take place with any of the aggregates found in Great Britain.[6]

The remaining minor ingredient of cements which is potentially destructive is tricalcium aluminate, which occurs in most portland type cements. This substance is a well defined crystalline material which forms about 5-15 per cent of most portland cements. It is stable in normal circumstances and is weakly cementive, forming with water a calcium aluminate hydrate. It can, however, form with sulphate, chloride, and other ions a series of complex compounds of the same general formula. One of these compounds is a calcium sulphoaluminate hydrate identical with the natural mineral ettringite. The formation of this compound as minute needle crystals inside a mass of hardened concrete causes steady expansion which in time results in a loss of strength and may finally disrupt the entire mass. This reaction can take place whenever liquors containing sulphates come in contact with hardened portland cement concrete and precautionary measures should be taken if the sulphate content of the liquor exceeds 0.05 per cent as SO_3. High alumina cement does not produce tricalcium aluminate hydrate and concrete made with this cement is highly resistant to the attack of sulphates. There are, however, suggestions that it loses its immunity to attack when it "inverts." In gypsum-slag cement the alumina present reacts during the hardening process to form calcium sulphoaluminate and there seems little tendency for further formation when more sulphate ions are available.

It is probably an over-simplification to state that the disintegration of concrete by sulphates is entirely due to reaction of sulphate ions with tricalcium aluminate hydrate. It may at least partially be caused by calcium sulphate formation[7]. Nevertheless, sulphate-resisting portland cement with its lower tricalcium aluminate content than the average for ordinary portland cements is certainly much more resistant to this form of attack.

Solutions containing chlorides can cause formation of the analogous calcium chloroaluminate. This compound is much more soluble than the sulphoaluminate and the destructive expansive crystallisation does not normally occur but concrete is weakened by exposure to concentrated calcium chloride solutions presumably because of the formation of this compound. Failures of concrete because of leakage of concentrated calcium chloride brine from refrigeration plant have been ascribed to this reaction.

The foregoing examples illustrate the major types of chemical attack on the bonding material in plain hardened concrete, but in reinforced concrete attention must also be paid to aggressive attack on the steel reinforcing bars.

If chemical attack on reinforcing steel merely affected the steel it might be said that further consideration would lie outside the scope of this paper. Unfortunately, attack on steel invariably produces corrosion products which occupy a greater volume than the original denser metal and this change in volume can generate pressures sufficient to disrupt the concrete surrounding the steel. Consequently, in reinforced concrete, aggressive agents which attack the steel not only lower the strength of the structure by reducing the load-carrying cross-section of the reinforcement but, what is ultimately more important, cause disruption of the surrounding concrete so providing entry points for further corrodant which causes increasingly rapid deterioration of the structure. It follows that in practice it is especially important to prevent the initial corrosion of steel bars. This can best be done by paying particular attention to the packing of the concrete round the steel and making sure that the location of the steel is correct so that no portion of it, including thin tie wires, is exposed at the surface or is within $\frac{1}{2}$ in. of it.

Mild steel used for reinforcement is very readily attacked by mildly aggressive agents such as water and atmospheric contaminants but is highly resistant to such attack in the strongly alkaline conditions encountered inside concrete. Consequently, as long as the steel is in good contact with concrete and is covered by it, it will be durable, but if it is not so protected it will corrode and may fail. This protection is lessened if there are high concentrations of chloride ions present and in such circumstances it is necessary to take particular care to ensure that steel is well protected by the surrounding concrete. Sodium chloride and calcium chloride are probably the commonest sources of chloride ions for promoting corrosion. Sea water contains about 3 per cent of sodium chloride and if concrete is to be exposed to it, or it is used for mixing concrete, particularly heavy cover to steel reinforcement is desirable; two or three inches cover is not excessive. Calcium chloride sometimes is used in concrete mixes to increase the rate of hardening but the proportion should never exceed 2 per cent of the weight of cement. If this recommendation is followed the corrosion of ordinary reinforcement is insignificant, perhaps because part of the calcium chloride combines with the cement and becomes less readily available to promote corrosion.

In prestressed concrete the situation is rather different. Here it is customary to use steel of very much slenderer sections and work hardened in such a way that the outer layer of steel in the wire is capable of carrying a greater stress per unit area than the core. As a result, if corrosion or pitting takes place to any given depth, the effect is relatively much more serious than in the case of the more massive and uniform mild steel conventional reinforcement. There is also the possibility that corrodants can cause stress corrosion cracking in the highly stressed reinforcement in prestressed units, with complete structural failure from a transverse crack rather than from a reduction in load-bearing cross-sectional area by pitting. For these reasons it is undesirable to use calcium chloride in prestressed concrete, particularly if it is to be steam cured, when any potentially corrosive reactions would be likely to be accelerated.

In normal prestressing practice where the techniques and supervision are good, corrosion troubles are rare, but where the protection of the reinforcement is neglected failure of the stressed member must be anticipated. It is especially important that in post-tensioned concrete units, where steel is not immersed in concrete but passed through a duct, great care should be taken to ensure that the duct is subsequently filled and the steel completely covered with cement paste. If any portion of the steel remains exposed to the air it will eventually rust and be liable to fail in tension.

The chemical effect of aggressive agents on reinforcement produces physical disruption of the concrete and this is a convenient point to consider physical attack.

Physical Attack

The principal physical phenomena which could affect concrete are temperature changes, action of various mechanical forces and atomic radiation.

Large changes of temperature generally have a destructive effect on concrete, but small changes, even over a large number of cycles, are not generally troublesome. Some of the destructive effect is due to differential movement brought about by the change in temperature, some by physical or chemical changes induced by the change in temperature.

The crystalline calcium compounds which bond concrete, except that made with high alumina cement, are not greatly affected by being heated at temperatures up to 100°C. but at higher temperatures they progressively lose water and their bonding power is impaired. In practice there is not much loss of strength and durability if concrete is exposed to temperatures up to 300°C. but at higher temperatures than this strength falls off rapidly[8]. This applies to portland cements and lime-slag cements and although there is little information about the behaviour of gypsum-slag cements they probably behave similarly. What is often more serious than this loss of strength through decomposition is the cracking which repeated cycling through large temperature differentials can cause. This arises normally because of the shrinkage of the concrete against restraint, initially as the concrete dries and later when it cools. Such cracking is naturally less severe if concrete is always under compression as in prestressed concrete units. Cracking of this kind may take place in the concrete of a unit but the unit as a whole remains structurally sound because the coefficient of thermal expansion of steel is fortunately close to that of concrete and little differential movement occurs on temperature cycling. Occasionally, however, repeated cycling can cause the concrete itself to disintegrate, presumably because differential expansion of the mortar matrix and embedded aggregate particles causes weakening and destruction of the mortar to aggregate bond. This effect is only met with when there is frequent cycling over a comparatively large temperature range, as for example in the concrete surrounding steam heating pipes.

With high alumina cement, the above picture is broadly repeated but in addition there is the possibility of deterioration because of the crystalline inversion already mentioned. It should be noted, however, that high alumina cement, if heated to 1000°C. or above, develops a ceramic bond in place of the hydraulic one and the new material which results is a valuable refractory concrete.

Low temperatures do not seem to cause any damage to concrete other than that which can be ascribed to the growth of ice crystals. Frost damage is well known and is a serious cause of the deterioration of concrete subjected to a large number of freezing and thawing cycles.

Various mechanisms have been proposed to explain how the damage occurs. In relatively dense concrete it is probably due to the expansion of water freezing in pores. In more permeable concrete it may be due to the formation of lenses of ice which grow as water diffuses to them through the material. It is not surprising that dense concrete of low permeability and porosity has good frost resistance but good resistance can also be obtained by incorporating about five per cent, by volume, of air in concrete. It is essential, however, that this air be uniformly distributed through the concrete in fine bubbles and it is the function of air entraining agents to control the size and distribution of these bubbles. Air entrainment is now practised on a large scale in countries where frost damage is prevalent and its value is widely accepted. The interpretation[11] of the benefits of air entrainment is complex but in simple terms it seems that the fine bubbles act as stress relieving voids into which ice crystals can expand. In this way the generation of higher pressures is avoided but in order to do this the bubbles must be small and very close together.

Most mechanical damage of concrete is caused by exceeding the compressive or tensile strength of concrete by impact or sometimes by direct loading but there are occasions when unforeseen localised dynamic stresses cause failures. In waterworks, mechanical erosion is often severe where solid matter such as stones and debris abrade the surface. Marine structures are particularly subject to this sort of damage and concrete, even if good quality, is not particularly resistant to attrition of this kind, especially when it accompanies mild chemical and frost attack. It is probably justifiable to protect concrete with a massive stone facing in such circumstances.

Cavitation effects can be serious as the local stresses developed can be high enough to tear the surface away from concrete and the remedy in such cases is to design the water flow system in such a manner that a streamline flow without low pressure zones is obtained.

Fatigue effects in concrete have only infrequently been considered, possibly because concrete is rarely subjected to frequent large load cycles. It seems likely, however, that prestressed concrete structures may increasingly be called upon to withstand transient stresses which are a substantial fraction of the total designed load-bearing capacity. In such circumstances one must take into account not only the fatigue properties of the steel reinforcement but also those of the concrete. Fortunately, the basic nature of hardened cement paste is one which seems likely to have good fatigue resisting qualities. If the picture of a matrix consisting of inter-tangled crystals as previously described represents the type of internal structure of the hardened cement paste, this is a structure much more likely to be able to withstand repeated stressing than a more ordered crystalline form. The little experimental evidence available[9] supports this view and suggests that in a conservatively designed reinforced concrete member the load carried by the concrete is unlikely to induce fatigue failure[10].

A generation ago, the effects of electromagnetic radiation in concrete could have been disregarded because the fluxes encountered were so small that their energy content was insignificantly low. Today, however, the artificial production of gamma radiation and intense neutron fluxes in industrial installations has made it necessary to consider what effect these phenomena may have on constructional materials.

Concrete absorbs neutrons and gamma radiation incident upon it and the absorption is accompanied by energy changes in the atoms of the material. Most of the energy lost by the neutrons or gamma radiation is converted into heat but some causes transmutation of elements, affects inter-atomic bonds, and has other side effects. Energy which is absorbed and not converted into heat produces changes in the physical properties of many materials and almost certainly has an effect on the strength of concrete. It has not, however, been possible so far to demonstrate such an effect because if it exists it has always been masked by the effects due to heating.

To summarise : Concrete is bound together by a crystalline matrix and destruction is caused by aggressive agents which attack the matrix. In the case of chemical attack this is most commonly caused by removal of lime from the calcium compounds which form the matrix.

All acids remove lime and are aggressive and organic compounds such as esters, which can be hydrolysed to acids, and polyhydric alcohols, which dissolve lime, act in a similar manner. Solutions of salts containing ammonium and magnesium ions are also aggressive because these ions exchange for calcium ions.

Sulphate solutions have a destructive effect on concrete containing tricalcium aluminate hydrate because of expansion caused by the formation of calcium sulphoaluminate.

Damage is also caused by expansive reactions resulting from delayed hydration of hard burned magnesia or lime in the original cement or from the expansive reaction of certain aggregates which is catalysed by alkalis in the cement.

Physical attack of concrete disrupts the crystalline structure and the commonest causes are temperature changes and mechanical stressing. Atomic radiation fluxes can also affect the structure. High temperatures cause shrinkage of concrete by loss of water and concurrent thermal expansion and may destroy the cementive compounds. Low temperatures chiefly cause damage by freezing uncombined water in concrete when ice formation leads to disruption. Mechanical stressing may be dynamic as with impact loading or may arise slowly because of pressures developed by corrosion of steel reinforcement ; in either case if the strength of the concrete is once exceeded permanent damage results. Concrete has probably inherently good fatigue resistance and damage due to cyclic loading is likely to be rare. Intense neutron and gamma ray fluxes probably damage the crystalline structure of the bonding materials in concrete but the possibility of such effects arising is confined to structures concerned with nuclear reactions.

This paper is presented by permission of Dr. A. R. Collins, M.B.E., D.Sc., M.I.Struct.E., Director of Research, Cement and Concrete Association, to whom the author is indebted for helpful criticism.

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Book Reviews

Foundations and Soil Properties, by Rolt Hammond. (London : Macdonald, 1961) 8½ in. × 5½ in., 181 plus vii pp. 30s.

It is rather felt that the title chosen for this book is not the best one. One expects to find yet another work on soil mechanics which might be described as " the mixture as before." In fact, however, the work fills a very useful, and possibly unique, function as a digest on that branch of soil mechanics known as geotechnical processes.

A digest would appear to be the most apt description, as the author has confined himself to the essential details of these processes, each of which could be the subject of a separate book. In this connexion, the somewhat meagre list of references is to be regretted. Any work which summarises a subject should be accompanied by as many references as possible to guide the reader towards more detail should he wish to delve deeper into the subject.

It is also felt that it is rather a pity that the author has attempted, in Chapters 1 and 2, to condense the whole field of geology and soil mechanics into 50 pages. Couched in a mixture of elementary and highly technical language, these chapters are of little value to those already familiar with the subject, and of little enlightenment to those who are not. It is also to be wondered what benefit a reader could derive from an illustration such as that on page 33, which depicts a typical " boffin " pouring something into a test tube.

Apart from these criticisms, the author is to be congratulated in producing a book which is most easy to read and understand, and one which should prove a most useful addition to the library of the practising engineer.

C. B. B.

Introduction au Calcul et à l'Exécution des Voiles Minces en Béton Armé, by André Paduart. (Paris : Eyrolles, 1961) 9½ in. × 6½ in., 95 plus viii pp. 18·75 N.F.

This small treatise by Professor André Paduart of the Université Libre de Bruxelles forms an introduction to shell design of all types.

The first four chapters can be read by any practising engineer and deal generally with the bases of concrete used in shell construction, but the following five chapters are necessarily highly mathematical and give the formulae on which each type is worked out, from cylindrical shells to thin roofs of double curvature, including parabolic hyperboloids.

The source of the equations is given in numerous references and the introduction mentions the advantages and disadvantages of the different types and also the difficulty of the calculations in most cases.

It is a concise book, very well produced, and is written in French. It would be invaluable to engineers working in this medium since it gives in one book the fundamental equations governing each type of shell.

L. T.

Le Chantier de Bâtiment et de Travaux Publics (Civil Engineering Sites), by Vittorio Zignoli (In French, translated from the Italian by A. Turin). (Paris : Eyrolles, 1961) 7 in. × 10 in., 660 pp., 304 figures, 134 tables 100·15 N.F.

The author of this book not only describes at length the different types of machinery in use on civil engineering works, but has also endeavoured to give the maximum practical information which is necessary for the consideration of various methods of execution or given works, such as open-air excavation, underground digging, underpinning, road making, surface transport, etc. The reader is thus in a position to choose the best solution, to plan the sequence of operations and to supervise their execution.

The great merit of the author is to have collected in one book a vast amount of data which could only be obtained by going through a great number of reference books. Numerous tables, which give the costs of materials or machinery operation, are particularly interesting, as they enable engineers and contractors to estimate the expenditure involved and compare possible solutions. Such tables contain useful information which can be adapted to particular cases by using the prevailing local prices.

It is especially a valuable reference book which will prove of great assistance to engineers and contractors desirous to introduce in their profession modern methods of work and organization in order to achieve greater efficiency on their civil engineering sites.

P. J. G.

The Design and Construction of Extension to British European Airways Base at London Airport *

Discussion on the Paper by P. B. Edwards, A.M.I.Struct.E., and R. B. Rigg

THE PRESIDENT introduced the authors, who then presented their paper. Mr. Edwards showed a series of pictures of the B.E.A. Engineering Base at the London Airport, and Mr. Rigg illustrated the method of construction and the general progress of the work.

Discussion

THE CHAIRMAN, proposing a vote of thanks to the authors, said they had presented what might well be described as being the ideal type of paper, as requested by many members of the Institution. It had covered design, planning and construction, and it had also given the opportunity to appreciate the ubiquity of structural engineering—in-situ, precast and prestressed concrete, tubular steel and other types. The meeting had also heard from Mr. Edwards that he had revised his opinion on the relationship between the aircraft engineer and the structural engineer; the President was very delighted to hear it, and it was a subject which he believed we should hear more about in the future.

Mr. J. H. HOLMAN showed a colour film illustrating the suspended crane tracks for carrying the underslung travelling cranes at the Engineering Base, referred to in the paper.

In the construction of the track each section was placed in a jig, where it was locked securely into position to prevent any distortion due to the heat generated. Welding was by an automatic arc process, giving a continuous weld over a maximum length of 60 ft. The surplus flux was drawn off and could be used again. Any distortion in the completed section was corrected by re-heating at certain points and allowing to cool.

The ends of the section were cut giving a clean profile which was then drilled for the spigot connecting each section of track. The tracks were joined by fishplates and short sections of channel welded to top of joint in track.

All cranes were contactor operated and controlled by two pressure push buttons operating on low voltage. Locking of the crane for transfer was completely automatic by pressing the push button at base of control pendant.

THE CHAIRMAN thanked Mr. Holman for showing the film, which gave not only some excellent views of the structure, but also an insight into some of the other engineering features connected with the building.

Mr. G. B. GODFREY (Associate-Member) observed that, although he had attended both meetings at which the papers forming the first two items in the bibliography to the present paper were presented, he particularly remembered the discussion which followed Mr. Harris's paper. Mr. Harris had been asked why prestressed concrete and not structural steelwork had been used for roofing the earlier B.E.A. hangars. He had given a number of reasons, probably the most cogent of which was that steel had been very scarce at the time. Nevertheless, Mr. Godfrey confessed that he had felt at the time it might be difficult to use structural steelwork in conjunction with the prestressed and reinforced concrete in the sub-structure without spoiling the appearance of the building.

It was now abundantly clear that, in a free market, structural steelwork was the most efficient medium for the spans involved in the present buildings. It was also possible to use such steelwork in such a way that it would be in sympathy with other structural media.

Mr. Godfrey asked the authors if they would kindly state what investigations they had made with regard to the relative economics of a structural steel roof, compared with prestressed concrete or aluminium or any other material. As much of the steelwork had been metallised he asked whether they would also state what they hoped to gain in maintenance costs by this method of protection.

He then showed a number of slides and described the construction and erection of the roof which comprised a combination of tubes and conventional rolled steel sections.

In the hangars themselves the transverse girders were of trapezoidal section, as shown in Fig. 5 of the paper. As they were so long, it was economically possible to vary the cross-section of the booms in a manner analogous to flange curtailment in a plate girder. Such variation of cross-section could be achieved either by varying the wall thickness or the outside diameter of the tubes. In this case the latter course had been adopted, there being tube reducers at the site joints at the third-points along the length of the girder. Typical details were given in the paper entitled "Joints in tubular structures" published in *The Structural Engineer* in April 1959.

Mr. Godfrey stated that in the hangars the unit weight of the roof steelwork was 7·5 lb/sq. ft. In the central workshops, where mono-rails were suspended from the roof, the weight was 10·8 lb/sq. ft., and in the south workshop, where there was also provision for under-slung cranes, the weight was 8·83 lb/sq. ft.

THE CHAIRMAN said the expansion joints in the frames had been very clearly indicated in the slides. But in the crane girders, as shown by Mr. Holman's film indicating the degree of precision with which they were erected, no such provision was made. He invited the authors' comments on that.

Mr. HAROLD EVANS (Associate-Member) referring to the fabrication of the crane girder, asked if the bottom boom were of high carbon content steel or of mild steel, and whether the contractors had experienced

* *Read before the Institution of Structural Engineers at* 11, *Upper Belgrave Street, London, S.W.*1, *on the* 26*th January*, 1961. *The President, Lt.-Colonel G. W. Kirkland, M.B.E.*(*Mil.*), *M.I.Struct.E., M.I.C.E., in the Chair. Published in "The Structural Engineer" Vol. XXXIX, No.* 1, *pp.* 17-31. (*Jan.* 1961).

difficulty due to the welding together of two different metals.

Secondly he asked whether the ends of two sections of the crane track where they had to be joined together, particularly the connexions at the cross-over, were machined elements or just sawn ends. He could foresee difficulty in a fixed end and a free end coming together, for a machined end was quite a different proposition from a sawn end.

Mr. REX I. SAVIDGE asked if the authors were able to indicate the level of natural illumination in the main hangar, and whether any readings had been taken since the structure was completed.

Mr. B. L. CLARK (Member) asked how the authors had dealt with the problem of providing fire protection for the steelwork as there had been great opposition in this country to the use of steelwork in hangars because of the fire risk.

Despite the installation of extensive deluge systems and fire detecting equipment, this opposition had been experienced with fire officers particularly and yet, here in the stronghold of such opposition, it was heartening to see that steel had been used.

The use of steel in this case had resulted in a building which was versatile in that it could be modified within limits, if aircraft designs changed drastically enough in the future, as in fact the signs already indicated.

The Americans tended towards the greater use of steel in their various open plan hangars because it was not too difficult a problem to modify the structure which, after all, was a small proportion of the cost of the aircraft fleets of the operating airline.

With regard to the under-floor heating, he said he did not know whether its installation was dictated by the clients or whether the engineers had considered other methods also; but it was by far the most simple method in buildings with large doors and large floor areas.

Mr. JOHN BENNETT (Member) asked what method was used in the hangar to restrain the crane tracks supported on the ball and socket hanger, in the longitudinal direction.

Were spring loaded tension devices used at the extreme ends of the track to damp out any tendency for the track to vibrate?

Mr. M. M. KHAN (Member), referring to expansion joints, said that at a steel mill at Sheffield, a very long and high building, he was told that it had no such joints, for they were quite unnecessary. In the building described in the paper there were expansion joints at intervals of 180 ft.

He asked whether the authors, if they had known what he had been told at Sheffield, would have considered having a structure with no expansion joints.

Mr. W. L. MURIEL commented that the Contract had been finished well within the time limit and well below the budget figure. Indeed it had been such a smooth running Contract that the meeting might be forgiven for thinking that no architect was involved. In fact there was, and judging from the fees paid he must have had quite a lot to do with it.

This Contract, he added, had been a very happy one and it showed what could be done with the Engineer, Architect and Constructor working closely together.

Mr. EDWARDS, replying to the discussion, dealt first with the Chairman's remarks concerning the provision of expansion joints in the frames. They were in fact a continuation of the construction joints formed in the hangar construction on 180 ft. module, and were continued across the width of the workshops because it was convenient to do so and also to limit the effects of movement of the structural framework. In view of the flexible form of attachment for the crane tracks it was considered satisfactory to omit the expansion joint in the length of the crane tracks.

Coming to Mr. Godfrey's question on the costs of the secondary roof girders, he said they did examine the costs of various alternatives—for example, reinforced concrete, aluminium and steelwork—but it was first of all necessary to draw a comparison between the first base and the one now under discussion.

At the first base the span of the secondary girders was 110 ft. and that of the main beams was 150 ft. In this project the span of the secondary girders was 132 ft., and the span of the main beams was 171 ft., from the centres of columns; so that there was a much larger area to be carried on the main beams, and greater span, than at the first base.

The problem was to keep the depth of the main beams to the minimum, because the greater the depth the more headroom would be needed in the hangars, and [illegible]t m ant increased heating costs etc. The main requirement of the clients was that there should be as much natural light as could possibly be provided on the hangar floor; the consultants had turned therefore to the lightest possible form of construction.

They had examined the costs and had found that at the time the lightness afforded by a tubular steel roof beam was amply justified, particularly as it was no more costly than any other type of beam of the same span. A prestressed beam would have limited the degree of natural light in the building very considerably, but perhaps the most important other factor was the relatively low reaction of the tubular steel roof beam on the main beam, and the corresponding saving in construction costs of the main beam.

Concerning Mr. Godfrey's point regarding metallisation of the tubular steel as opposed to conventional painting, Mr. Edwards said that painting 54 ft. above the floor would be quite an expensive operation; not only that, but it was something which the clients did not wish to undertake at too frequent intervals. Assuming the use of a painting process, consisting of two primers, an undercoat and a finishing coat, something like 7-10 years' life might be expected in the atmosphere at London Airport, whereas if the tubular steelwork were metallised then a much longer life might be expected, perhaps as much as 15 years. A cost comparison showed that the tubular steel frames, metallised, were not a great deal more than the cost of ordinary prestressed concrete secondary beams.

In reply to Mr. Evans's point concerning the fabrication of the crane girder, the bottom flange was a high carbon steel section welded to a mild steel web by means of a continuous flux welding system. There was no evidence to show that there was any difficulty in jointing the two different types of metal and the performance of the compound section had been entirely satisfactory.

Replying to the question on the two sections of the crane track where they had to be joined together, there was allowed in the installation a $\frac{1}{4}$ in. gap between which was bridged satisfactorily by the wheels of the crane bogies. In the case of the fixed transverse section situated between each 100 ft. width bay, no movement could take place in this unit as there was no expansion

joint in the roof structure in the width of the workshops. The ends of the crane track were all sawn on a special cutting machine.

Replying to Mr. Savidge's question concerning the natural illumination in the hangars, he said that readings were taken and these indicated a lighting value of 400 ft candles on the hangar floors.

On Mr. Clark's question concerning fire protection for the steelwork, a deluge system was installed, and those who had been fortunate enough to see it in operation felt that no fire could possibly reach serious proportions. The system could be operated by bursting of the sprinkler heads due to an increase of temperature around the head and also by the " Fyretron " system. This latter system consisted of an electrical circuit in which there were two wires with an electric current between them. As soon as the temperature around the wire increased, the resistance across the wires was decreased, causing a voltage drop which set off a series of contacts which operated a solenoid valve on the main water supply ; compressed air was injected into the pipes and water was forcibly ejected from the deluge sprinkler heads. Each hangar was split into two sections, so that the whole area of a hangar would not necessarily be deluged at once. The Insurance Companies required to be satisfied on the operation of the deluge system, and a live test in two bays was carried out satisfactorily.

As to why under-floor heating was used, his mechanical engineering colleagues could probably answer best ; he, himself, was not very well qualified to do so. But a floor heated in this way gave an even heating over the whole area. Over each of the main doors there were two heaters which were turned on automatically when the doors were opened, giving a blanket of hot air right across a hangar. Also at the rear of each hangar there were unit heaters, under thermostatic control, backing up the general ambient warmth provided by the under-floor heating.

Replying to Mr. Bennett's question concerning vibration of the centre crane tracks, he said that when the tubular roof frames were first designed it was intended to put in a system very different from the one that had now been installed. During the early part of the construction work the clients had indicated that they wanted a flexible crane system, involving the use of a number of hoist units. This led to providing additional fixings to the already erected steel framework and also additional loading. A major factor in the choice of the suspension crane system finally installed was the cushioning effect, afforded by the special type of suspension bolts, on the roof framework.

Mr. BENNETT said he was referring to the movement of the crane track longitudinally. He asked whether a method was used whereby a fixing could be provided at each end to prevent vibration.

Mr. EDWARDS said that was not done. There were hangers at every 20 ft., which were quite sufficient to take care of longitudinal movement.

Mr. Khan had referred to the problem of expansion joints. The decision to put them in at intervals of 180 ft. was dictated by the main beams, as they were free to move in the direction of the span to allow for expansion and contraction. As he had mentioned in his introductory remarks, the hangars were designed as a unit, i.e., the beams, the columns and the rearward columns. It would therefore, in the circumstances, be better to call them both construction and expansion joints. As the workshops lay between each block of hangars it seemed sensible to continue the joints on the same module through the workshops.

THE PRESIDENT, on behalf of the meeting, thanked Mr. Edwards for his very able reply to the discussion.

Structural Engineering in Nigeria*

Discussion on the Paper by A. Brimer, M.I.Struct.E.

Discussion

THE CHAIRMAN proposed a vote of thanks to the author. Commenting on Mr. Brimer's apology for having omitted mathematics from the paper, the Chairman said he need not have apologised, for there were some who felt that on occasions such an omission provided the opportunity for members to think more broadly. In any case the Institution was interested in the promotion of the science *and art* of structural engineering, and perhaps Mr. Brimer had put forward some of the art instead of some of the science.

The members were very grateful to him for having contributed the paper, for it had been very interesting to read it and to hear his remarks on what was being done in a country overseas.

THE CHAIRMAN welcomed to the meeting members of the Nigerian Society of Engineers, headed by their President, and hoped they would join in discussion.

Mr. J. F. D. WOODS asked why, in a building of about 20 storeys which had been illustrated, steelwork was used, whereas reinforced concrete was used in another.

Mr. BRIMER replied that the buildings he had illustrated were not entirely the work of his own firm. The building referred to by Mr. Woods was designed by Oscar Faber and Partners, and his own firm were not the designers, therefore he could not give any information. He could perhaps suggest a reason, but he would rather not.

Mr. L. E. WARD (Member of Council) said the indication the author had given of the relative costs of steel and concrete construction in Nigeria was very interesting, and added that in this country concrete construction was generally regarded as the thing for multi-storey buildings.

One had noticed that nearly all the illustrations given when presenting the paper were of multi-storey buildings and there were not many showing single-storey buildings. He asked what type of construction was used for the latter in Nigeria, and also why

* *Read before the Institution of Structural Engineers, at 11, Upper Belgrave Street, London, S.W.1. on the 12th April, 1961. Mr. F. R. Bullen, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., (Vice-President) in the Chair. Published in " The Structural Engineer," Vol. XXXIX, No. 4, pp. 117-123.*

multi-storey buildings were erected in a country where land seemed to be so plentiful.

Mr. BRIMER could not give the answer concerning the relative costs between reinforced concrete and steelwork construction for a very large building because the one he had illustrated was the first and it was not yet completed. The steelwork, of course, had to be clad, and that was very expensive, for shuttering had to be used, and that was one of the most expensive items in construction. The concrete was quite cheap as compared with the shuttering; the latter cost something like £1 to £1 5s. 0d. per square yard.

He had illustrated multi-storey buildings because he had felt it would be of interest to see that such structures were built in Nigeria. But the bulk were of two-storey construction. It was usual in these buildings to use 5 in. to 7 in. thick solid concrete floor slabs, load bearing sand cement block work and possibly timber for the roof construction. Very often double-storey buildings were erected with simple reinforced concrete portal frames, empanelled with block work or something similar.

The main reason why timber was not suitable was that seasoning and treatment was not done in Nigeria. Timber was expensive due to the heavy transport costs by road as against using the creeks and inland waterways, to get it to building sites. Timber from the United Kingdom could be cheaper than that grown in Nigeria. In the very, very dry season timber was likely to crack and twist, and it was not wise to use it in any respect in the North.

Mr. IFEDAYO AKINTUNDE, asking for information concerning foundations for buildings in Nigeria, said that most of the slides shown illustrated buildings on raft foundation. Did piling present some peculiar difficulties in Nigeria?

Mr. BRIMER replied that quite a lot of piling was used, and he referred to an 11-storey block of flats which was built on piles. More or less all the known variations in foundation work had been tried during the last four or five years, including compaction, which was quite new to Nigeria; he believed it was first used there two years ago, and it had proved very successful. But the extent of its application was very limited; he estimated that only about 20 per cent of the area in Lagos was suitable for compaction, the rest being swamp, where it was necessary to use piles or some other means. In some cases it had not been possible to find the bottom of the swamp until a depth of about 80 ft. was reached. That was why trouble was being experienced with a road which, in 18 months, had already settled 10 or 12 ft.

Mr. A. A. POPOOLI asked if the author could enlarge on his reference to troubles with piling and the variation of the stresses which could be applied to the concrete in relation to the quality of the cement used.

Mr. BRIMER replied that that part of the paper related only to Lagos, the only town in Nigeria which had any sort of by-laws that were really used. There had been a great battle between himself and the Town Engineer to get them changed slightly, and about four years ago they were changed, but he had found subsequently that the change was not always advantageous.

Lagos had formed a special Structures Committee, and the position was that if one wanted to design a structure on which the imposed stress was more than 600 lb/sq. in. one must apply to the Committee for permission. If one wanted to use 750 lb/sq. in., the Committee insisted on the employment of a part-time Resident Engineer, and if one wanted to use 1,000 lb/sq. in they insisted on the employment of a full time Resident Engineer.

He personally, unless he was doing a job of any size, where a fully qualified Resident Engineer could be employed on the site, would not use stresses above 750 lb/sq. in. anywhere in Nigeria. He had in mind the problems which had arisen when using a particular cement in the past, which had taken as much as three months to reach a site in Nigeria and it was not in very good shape when it arrived there.

Mr. A. A. POPOOLI said reference had been made by Mr. Brimer to a building which had been pulled down and a new one erected. He asked if such experiences were very frequent.

He also invited the author to say more about the high water table in some areas.

Mr. BRIMER said the building referred to was St. John's school at Alloya. Unfortunately, he was asked to make a report for the Ministry of Education concerning the building and he had asked for the foundations to be opened up for inspection. When he had got there he had found that the building had no foundation whatsoever. Originally the ground had been excavated; some very large rubble, broken bricks, sand and cement had been thrown into the water, but it had disintegrated. The school building had split completely in about six places and it was almost at the point of falling down. The Town Engineer had condemned it.

The water table at Apapa was 1 ft. or so below ground level, and at Tinubu Square the water table was about 9 ft. below the surface, due mainly to the rising ground, about 14 ft. above sea level.

LT.-COLONEL R. HAZZLEDINE, O.B.E.(Mil.), T.D. (Member), asked what were the stresses allowed for precast factory made reinforced concrete units, and for prestressed concrete.

Mr. BRIMER said that a prestressed concrete flyover bridge was designed for 6,000 lb/sq. in., but there was great difficulty in attaining it and it was re-designed to a lower stress. In preliminary tests some very good cubes were produced, but on the working site it was very difficult to maintain the standard, so that the design stress was lowered and the beams were re-designed.

There was virtually no precast concrete made in Nigeria. There were two so-called precast works; one of them made thousands of sand cement blocks and the other turned out a prestressed electricity pylon. That represented practically the whole of the precast work; it was needed, but it was very difficult to get people really interested.

Mr. E. OLUWOLE asked a question concerning the training of Nigerian engineers in Nigeria and in this country.

Mr. BRIMER replied that one of the reasons for forming a Section of the Institution there was to see what could be done to help the Nigerians in Nigeria, not so much those who came to the United Kingdom. He believed that most of the consulting engineers had men from Nigeria working in their offices for some years; his own firm had six or seven in London. The Nigerian Government had their own scheme for sending their men to this country on scholarship courses and trying

to fit them into London consultants' offices afterwards. Anyone who had the opportunity to look into this scheme would appreciate that quite a lot was being done.

He felt that Nigerian engineers needed to work here for probably two of three years and then go back to Nigeria. The trouble was that there were not enough consultants in Nigeria with sufficient Nigerian experience to train them, and it was that experience which the Nigerians needed most, rather than too much European experience.

Mr. M. O. EBIZIE asked for information concerning the water table at Lagos.

He also asked about corrosion problems which had arisen in swampy areas, whether they were due to sulphur in the water.

(a) His experience was that the water table at Lagos rose with the rains and fell during the dry season.

(b) He wondered why high alumina cement which was resistant to sulphates was not used in Lagos when founding on swamps.

Mr. BRIMER said the water table rose and fell according to seasons. At the particular site mentioned it did not go below 18 in. from the surface, and in the rainy season it came up nearer to the surface. At Ikeja its level was fairly constant at probably 2 ft. down, but it rose 6 or 7 in. above that in the rainy season.

At South East Ikoyi, where there had been some reclamation of land, roads and drains were laid and within a few months some of the drains had completely disintegrated; that was due to sulphur in the water of the swamp. There was also severe corrosion of the steelwork. There were several very good examples of it in the Nigerian Ports Authority's office; 2 in. bolts, 9-15 months after being fitted, could be pushed completely through the holes, the heads having disappeared completely.

Mr. J. R. LOWE (Member) asked if the author could give an idea of the parts of Nigeria in which the soil was suitable for vibro-compaction. Where this method was now available presumably the previous alternative was a piled foundation. Could the author give some idea of the relative costs of the two methods? In some of the illustrations which Mr. Brimer had shown there appeared to be a considerable amount of modern construction plant in use, such as tower cranes and mobile cranes. Was the use of such plant general in Nigeria or was it restricted to the main towns such as Lagos? Was the use of earth moving and road construction plant general throughout the country?

Mr. BRIMER, dealing with the comparative costs of compaction and other types of foundation construction, said he could not remember the actual figures obtained when this matter was examined, but compaction was quite a fair amount cheaper than piling on the particular site used. He recalled having mentioned also that, particularly in Lagos, compaction had very limited use. The coastal range was a delta and it was almost completely an inland waterway system; one came up against sand or swamp. He thought there was still a prospect up north. There was a problem in Sokoto, where they had not managed to prevent a building moving.

The modern construction plant mentioned by Mr. Lowe was typical of Lagos only. The use of that type of plant, and even scaffolding, on a high building had come about only in the last 18 months or two years.

Mr. LOWE asked about road construction.

Mr. BRIMER replied that road construction plant was far more modern; but they had not gone far beyond plants, such as the Barber-Greene machine.

Mr. L. MBA asked a question on foundation works.

Mr. BRIMER replied that in respect of foundations the coastal region was very much like Lagos. Further north we came to a clayey material which was quite good for foundation works. There might be a sort of saucer of that material and on the very edge of the saucer we should find just sand—and it was moving sand. On the plateau there was quite a good rock, but it was very patchy and one was likely to have half a building on rock and half of it on sand, unless one was very careful.

With regard to the second part of the question, he said he had solved the problem by putting in air conditioning.

Mr. M. I. KAZIE remarked that in this country there was a clear division between consultant and contractor, whereas in Nigeria the division was not so clearly marked. He asked if the author considered that in a country such as Nigeria it would be better for the engineering profession as a whole to adopt the British engineering division.

Mr. BRIMER said that in his practice the contractors and consultants worked separately; that was a system which worked quite well and he thought the Nigerians, from their own point of view, should insist on carrying that out.

THE CHAIRMAN said that if vibro compaction was used or, as he believed it was called, vibro flotation, the density of the upper layers was increased, so that he asked what happened to the under layers of the ground; was there any marked settlement? It seemed to him that the effect of the vibration was to constitute a sort of raft, and therefore there must be a settlement problem. In the author's interesting photographs of the process of vibro compacting there was a pipe running around the top of the excavation, and Mr. Bullen wondered whether this was part of a well point system. If not, had the author tried well points?

Was it right to think that in many cases piles were not used because they would have to be 180 ft. long? Was that the sort of approach to the problem if there were no sort of foundation at a reasonable depth.

Mr. BRIMER, coming to the question on vibro compaction, asked if Mr. Bullen were referring to the amount of settlement that occurred during the actual compaction.

Mr. BULLEN said he meant the settlement after building.

Mr. BRIMER replied that the ground was estimated to be able to carry about half a ton per sq. ft. before compaction, and they had tried to compact it to carry more than 2 tons per sq. ft. He thought the settlement would be about $\frac{1}{8}$ in. or even less.

There were no well points in the case mentioned by Mr. Bullen, and he did not know what the equipment was. He had used the well point system in Nigeria and it had been successful. He knew of only two contractors with well point plant; one could not easily encourage contractors to bring more plant, and it was very difficult to get them to use the well point system.

Concerning piles, he had contacted only two extremely bad sites, but no doubt there were more. The length of piles he had used was 30-35 ft., and they were driven quite comfortably. He did not think the ordinary piles were more than 45 ft. long.

Mr. WALTER C. ANDREWS, O.B.E. (Past-President), discussing labour costs in Nigeria, said the rates were considerably lower than in this country, and the output, for various reasons, was roughly proportionately lower, so that the cost per unit of work done was about the same as here. The higher cost of cement was almost counterbalanced by the lower cost of sand.

For structures generally the cost per foot cube was approximately the same as in this country. That was a generalisation, which came about largely because the finishings were simple. In the simpler buildings the cost of the structure bore a considerably higher proportion than that taken up by surfaces and finishings. So that, whereas the cost of the structure here might be anything from 15 to 25 per cent, in Nigeria it started at 25 per cent, and he mentioned a case where it had been as much as 40 per cent. The general average was 33⅓ per cent.

With regard to the comparison between structural steelwork and reinforced concrete, the 16-storey building illustrated in the paper was originally intended to be of structural steelwork, but a comparison of two designs was made and the reinforced concrete design came out 15 per cent cheaper. The steelwork figure was based on tenders, and the concrete version was based on estimates subsequently confirmed by tenders.

For the foundations a comparison was made between the costs of compaction and piling on the basis of using 40 ft. piles, and the vibro compaction scheme was cheaper. A factor influencing the decision was that they were by no means certain that a pile length of 40 ft. would be enough. But for that particular site and the one adjoining it there was no question that vibro compaction was the right solution.

There was the question of settlement, of course, and that was provided for by a stiff raft on the vibro compacted ground.

Mr. J. A. OLANIYAN (Graduate) asked if structural work was being done in parts of Nigeria which was not mentioned in the paper.

He also wanted to know whether engineering bricks or stucco bricks were being made in that country and, if so, how they compared with bricks produced in Britain in terms of price, quality and appearance.

Mr. BRIMER said he did not know of any major town in Nigeria which had not a modern building. Structural work was being done all over Nigeria.

He was very interested in the question as to whether there were brick manufacturers in Nigeria. The answer was 'No.' But he had looked into this matter during the last six months or so and hoped to do so again, and he thought that bricks of quite good standard could be produced there. They would probably not reach the standard of the top class as we knew it in this country, but they would reach a very good standard, far better than the ordinary Fletton. There were plenty of clay deposits suitable for this purpose both in the west and the east, and he did not see why brickmaking could not go with a swing in Nigeria. In the small towns the people produced their own local bricks, the materials being mixed by hand, and baked; they were very soft, but the people built their own homes with them.

Mr. A. A. POPOOLI asked what Mr. Brimer thought of the prospects for the structural engineer in Nigeria.

Mr. BRIMER said he believed the Nigerian Government had turned down, not a loan, but an offer by the British Government to supplement the salary which the Nigerian Government would pay to U.K. Personnel. He could not give his views on that from the political point of view; but it might have an effect in turning engineers away from the Government Departments, where engineers who had gone out to do engineering jobs were usually tied down for the rest of their lives to work which was mostly administrative. Nigeria was terribly short of its own people as engineers. In his opinion there was a tremendous gap between the qualified engineer and the ordinary draughtsman.

Mr. POPOOLI asked if he could see any hope.

Mr. BRIMER said the only hope was that we could encourage more Nigerians to become engineers. There seemed to be a great world shortage of engineers, and it was very, very expensive to keep a European in that country, somewhere in the region of £4,000 a year; it was not possible to continue to do that. There must be Nigerians to help out.

THE CHAIRMAN said the discussion had been very interesting and vigorous. He thanked all who had taken part, and particularly Mr. Brimer, not only for his paper, but also for replying to the questions so admirably.

Institution Notices and Proceedings

GENERAL MEETING

A General Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1. on Thursday, 5th October, 1961, at 6 p.m., when the Presidential Address for the Session 1961-1962 was given by Mr. F. R. Bullen, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E.

Lt.-Colonel G. W. Kirkland, M.B.E.(Mil.), M.I.Struct.E., M.I.C.E., (the retiring President) was in the Chair.

After welcoming the guests, the Chairman introduced Mr. Bullen to the meeting and invested him with the Presidential Badge of Office. He wished him a very happy year as President and Mr. Bullen then took the Chair.

Dr. D. D. Matthews, M.A., M.Sc.(Eng.), D.Eng., M.I.Struct.E., M.I.C.E. (Vice-President) proposed a vote of thanks to Colonel Kirkland for his services as President of the Institution during the past Session. He referred to the tour which Colonel Kirkland had made on behalf of the Institution during the summer recess, in the course of which he had travelled no less than 33,000 miles and had visited the Republic of South Africa, Rhodesia, Kenya, India and Malaya. The members of the Institution owed him their thanks for the splendid success with which he had carried out that tour, as well as his many other duties as President.

Mr. F. M. Bowen, M.I.Struct.E., M.I.C.E., Assoc.I.Mech.E., (Vice-President) seconded the vote of thanks and the President then presented Colonel Kirkland with a Past-President's badge.

Colonel Kirkland expressed his thanks and his appreciation of the remarks which had been made. He then occupied the Chair, at the request of the President, who presented the Presidential Address. (The Address is printed in this issue. When delivered, it was accompanied by fifty illustrations, but for publication it has been necessary to reduce this number to thirteen.)

Mr. J. GUTHRIE BROWN, M.I.Struct.E., M.I.C.E. (Past President), proposing a vote of thanks to the President, said the Address had been a great success and an outstanding achievement on a subject of fundamental importance to all structural engineers. There had obviously been a vast amount of research put into the preparation of the Address and members were deeply grateful to him. Mr. Guthrie Brown wished the President every success during his year of office.

Mr. BRIAN SCRUBY, M.I.Struct.E. (Vice-President), seconded the vote of thanks.

THE PRESIDENT resumed the Chair, at the invitation of Colonel Kirkland, and expressed his appreciation of the kind remarks which had been made. He then referred to the retirement of Major Maitland from the office of Secretary of the Institution, an office which he had held for over 31 years. During that time, the Institution had grown from 3,000 to 9,000 members, its prestige and importance were recognised by the Government and by the general public both in this country and overseas, and membership signified accomplishment in the art and science of structural engineering.

In appreciation of Major Maitland's services to the Institution, a testimonial fund had been inaugurated by Colonel Kirkland and tangible expression of the Institution's goodwill would be given at a dinner to be held on the 2nd November. The President wished Major Maitland good health, long life and happiness. He would not disappear from the scene, for he would become the Institution's Consultant, so that it might continue to have the benefit of his wide experience, his wise guidance and unfailing support. The President concluded by expressing to Major Maitland the good wishes of the members and thanking him for the good work he had done over the past 31 years.

MAJOR MAITLAND, O.B.E., M.I.Struct.E., in a brief response, said it was really too kind of the President; for several months he and his colleagues had been making many all too flattering statements concerning his 31½ years of office as Secretary. No Secretary, however competent and devoted to the interests of the Institution, could have had any small success without the continued help and confidence of successive Presidents and Council members, in addition to the splendid support and loyalty of his senior staff.

ORDINARY MEETING

An Ordinary Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1., on Thursday, 12th October, 1961, at 6 p.m. The President, Mr. F. R. Bullen, B.Sc., M.I.Struct.E., M.I.C.E., was in the Chair.

The President introduced the new Secretary of the Institution, Mr. C. D. Morgan, F.C.I.S., and expressed good wishes to him on behalf of the members. Mr. L. R. Creasy, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., presented a paper on "Professional Practice and Drawing Office Procedure." The paper was published in the October issue of the *Journal* and a report of the discussion which followed its presentation will appear in a later issue.

ORDINARY GENERAL MEETING

An Ordinary General Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1. on Thursday, 26th October, 1961, at 5.55 p.m. Mr. F. R. Bullen, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E. (President) in the Chair.

The Minutes of the Ordinary General Meetings held on the 25th May and 22nd June, 1961, as published in the Journal, were taken as read, were confirmed and signed.

The following members were elected in accordance with the Bye-Laws. Will members kindly note that the elections, as tabulated below, should be referred to when consulting the Year Book for evidence of membership.

GRADUATES

CHAKRABARTI, Kamalakanta, of London.
GLYNN, Christopher Patrick, of Nairobi, Kenya.
NEWCOMBE, Peter Sturgeous, of Melbourne, Australia.
O'MAHONY, Timothy Joseph, of Dublin, Ireland.

ASSOCIATE-MEMBERS

ABRAHAM, Albert Arthur, of Petts Wood, Kent.
AFFLECK, Michael John, A.M.I.C.E., of Purley, Surrey.
BAILEY, Peter John William, of Crawley, Sussex.
BICKNELL, Brian David, of Curdworth, Warwickshire.
BISHOP, Ernest John, of London.

BLACK, Graeme, B.Sc., of Largo Ward, Fife, Scotland.
BROWN, Williams Patrick, of London.
CALLAGHAN, George Denis, B.Sc.(Eng.), of Birmingham.
CHEN CHIEN HAI, B.Sc., of Kowloon, Hong Kong.
CHEONG YI CHOON, of Singapore.
COAPES, William Donald, M.Sc., A.M.I.C.E., of Newcastle upon Tyne.
CORNWELL, Dennis Frederick, of Ashford, Middlesex.
COWLEY, Donald Holliday, of Manchester.
EDDISON, John Michael, B.Sc.(Eng.), A.M.I.C.E., of Aberdeen.
FENNER, Raymond Michael, of Croydon, Surrey.
FILMORE, Maurice Ernest Fuce, of South Ascot, Berkshire.
GARDNER, Richard Pringle McKay, B.Sc.(Hons.), of Edinburgh.
GHOSH, Syamal Chandra, B.E., of Calcutta, India.
GLINIECKI, Leszek Feliks, of Carshalton, Surrey.
GOFF, Derrick Claude, of Reigate, Surrey.
GRIMMOND, Roland Arthur James, of Morden, Surrey.
GROENEWALD, Hermanus Bernhardus, B.Sc.(Eng.), of Nairobi, Kenya.
HAMILTON, Donald Winstanley, of Matlock, Derby
HARWOOD, George Alfred, of Bristol.
HILL, John, of Woking, Surrey.
HOLLAND, Jack, B.Sc., of Welwyn Garden City, Herts.
HOOD, Anthony Paul, of Forest Hills, Long Island, New York.
KHALIQ, Mohd Abdul, of Tejgaon, Dacca, East Pakistan.
KIRPALANI, Murli Bulchand, B.E., of London.
KROLIK, Stanislaw, A.M.I.C.E., of London.
LARK, Victor George, B.Sc., of Cheltenham, Glos.
LINDSAY, Richard Herbert William, of Mitcham, Surrey.
LOZINSKI, Zygmunt Adam, B.Sc., of London.
MCCRACKEN, William Weir, of Bridge of Allan, Stirlingshire.
MANNING, Brian George, of Bromsgrove, Worcs.
MEANWELL, Ronald William, of London.
MIKA, Tadeusz, B.Sc.(Eng.), of Ebute Metta, Nigeria.
MILLAR, Stuart Greig, of London.
MILLS, Henry George James, of Stansted Mountfitchet, Essex.
MURCH, Peter Walter, of Potters Bar, Middlesex.
NORFOLK, John Henry, of Surbiton, Surrey.
OBOSI, Louis Oranye Ezeudu, of Lagos, Nigeria.
OLADEJI, Emmanuel Olaniyi, B.Sc.(Eng.), of London.
OMOTOSO, Iyiola, of London.
PARSONS, Patrick, B.Sc., of Wylam, Northumberland.
PERCIVAL, John Adrian, B.Sc.(Eng.), A.M.I.C.E., of Sanderstead, Surrey.
PORTER, Robert George, of Aberdeen.
QUIN, Neil, of Bramhall, Cheshire.
RODRIGUES, Braz Maria Constantino De Assuncao, B.Sc., of Nairobi, Kenya.
ROWE, Walter Ernest, of West Kingsdown, Nr. Sevenoaks, Kent.
SAFIER, Armand Simon, B.Sc.(Eng.), A.M.I.C.E., of Edgware, Middlesex.
SATHE, Ramachandra Mahadeo, B.E., of Dist. Satara (North), Bombay State, India.
SCHOLFIELD, James Clement, of Chalfont St. Peter, Bucks.
SOMES, Norman Frederick, B.Sc.(Eng.), of Barnehurst, Kent.
STANNARD, Robert Francis, of Sidcup, Kent.
STYLES, Ronald Walter, of Ashford, Middlesex.
TAY KWANG SENG, of Johore, Malaya.
THOMAS, Peter John, of Ilford, Essex.
TOEG, Victor Meir, B.Sc.(Eng.), of London.
TREGEAR, Keith, of Nairobi, Kenya.
TSUI KIN MAN, B.Sc.(Eng.), of Causeway Bay, Hong Kong.
WALKER, Leonard, of St. Helens, Lancs.
WIESMEYER, Hans Leo, of Johannesburg, South Africa.
WILSON, Graham, A.M.I.C.E., of Dumfries, Scotland.
YOUNG, Reginald Alfred, of Petts Wood, Kent.
YUAN TAO MING, B.Sc., Port of Spain, Trinidad.
ZLOTOPOLSKY, Shlomo, of Tripolitania.

TRANSFERS

Students to Graduates

AH-KEE, Roger, of London.
EXTON, John, of Crich, Nr. Matlock, Derbyshire.
MEHTA, Ramanlal Makanji, of Dist. Surat, Gujarat State, India.
MORLEY, Peter Stuart, of Allestree, Nr. Derby.
SEN GUPTA, Digendra Kumar, B.Sc., of Calcutta, India.
STANBRIDGE, Graham John, of Burton on Trent, Staffs.
TEASELL, James Sinclair, of London.

Student to Associate-Member

TAN YORK HING, of Johore, Malaya.

Graduates to Associate-Members

BAGCHI, Matindra Nath, B.E. of Dist. Burdwan, W. Bengal, India.
BANDYOPADHYAY, Amarendra Mohan, B.E., of Manchester.
BARRATT, Gordon, of Cheadle, Cheshire.
BARRON, Gerald Percival, B.Eng., of London.
BEDFORD, John Lewis, A.M.I.C.E., of Barkingside, Essex.
BELL, Colin Walter Herbert, of Boxmoor, Herts.
BELL, Harold, of Epsom Common, Surrey.
BERRY, John Graham, B.A., B.A.I., A.M.I.C.E., of Great Bookham, Surrey.
BLACKBURN, Michael Peter, of St. Alban's, Herts.
BOTTOMLEY, Kenneth, of Billingham, Co. Durham.
BUDWORTH, Captain George Joseph, R.E., of Morecambe, Lancs.
BUKY, Karoly, of Peterborough, Northants.
CALLAGHAN, Brian Frank, of Heaton Chapel, Stockport.
CARRICK, John Leslie, of London.
CHANDRA, Tirtha Renu, B.Sc., of Calcutta, India.
CHANG, Tai Hon Philip, B.Sc., of Hong Kong.
COOPER, Raymond Barrie, B.Sc.Tech., of Marple, Stockport, Cheshire.
DAVIS, Charles James, of Woking, Surrey.
DOWLING, Peter Alexander George, of Overport, Durban, Natal.
EDWARDS, John Joseph, of London.
FREEMAN, Anthony John, of Hornchurch, Essex.
GEE, Brian Lewis, B.Sc.Tech., of London.
GIBBONS, Barrington, of Thornton Heath, Surrey.
GILCHRIST, James, B.Sc., of Hooton, Wirral, Cheshire.
GOODWIN, Harry, of Cambusbarron, Stirling, Scotland.
HANNON, James David, of Darenth, Kent.
HARPER, Alfred George, of Hullbridge, Essex.
HOLT, Eric John, of Enfield, Middlesex.
HORLER, Tom Leslie, of Cross-Keys, Mon.
HUNT, Anthony James, of Wallingford, Berks.
HURDLE, Anthony William, of Ashford, Middlesex.
JACK, William Sommerville, of Glasgow.
JENKINSON, Geoffrey Eric, B.Sc., of Hatfield, Herts.
JOHNSON, Colin Lionel, B.Sc.(Hons.), of Birmingham.
JONES, Henry James King, A.M.I.C.E., of Newbury, Berks.
KAMAT, Bhalchandra Achyutrao, B.E., of London.
LECK, George Yuill, B.Sc., of Pollokshields, Glasgow.
LI PAI LIN, B.Sc.(Eng.), of Hong Kong.

LOZINSKI, Artur Jerzy, of London.
MACFARLANE, John, of Port Elizabeth, South Africa.
McLOUGHLIN, Kevin Joseph, B.E., of Loughrea, Co. Galway, Eire.
McPARTLAND, Michael John, of London.
MARSHALL, Kenneth Arthur, of Copthorne Bank, Nr. Crawley, Sussex.
MATTOCKS, Ronald, of Kemsing, Kent.
MEEK, William Charles, of Wellington, N.Z.
MENEHAN, Kevin John, of Morden, Surrey.
MERRAN, Sidney, of Enfield, Middlesex.
MILLARD, Francis Edward, of Dagenham, Essex.
MORGAN, Robert Evan, of Saltford, Nr. Bristol.
MORGAN, Rotimi Modupe, B.Sc., of Sapele, Nigeria.
MORRISSEY, Frederick Walter, of London.
NEKOO, Rustom Keikhusroo, B.Sc., of Nairobi, Kenya.
NOWELL, Leonard Ewart, of London.
PANG KIA CHOON, of London.
PATRICK, Colin Desmond, of Durban, South Africa.
PAUL, Peter Richard, B.Sc.(Eng.), of Maidenhead, Berks.
PEEL, Roy Albert, B.Sc., of Sutton Coldfield, Warwickshire.
PORTER, Alan George, of South Croydon, Surrey.
PORTER, John Ellis, of Beckenham, Kent.
PRINCE, George Arthur Joseph, of London.
PROBERT, Leslie Anthony, of London.
PRODROMOS, John Philip, of Beirut, Lebanon.
QUINN, Felim, B.Sc., of Newry, Co. Down.
REES, Michael Howell, B.Sc.(Eng.), A.M.I.C.E., of Sunbury-on-Thames, Middlesex.
REMEDIOS, Cleto Anthony, B.E.(Civil), of London.
ROESSLER, Alfred Frederick, of Billericay, Essex.
ROONEY, Dermot Francis, B.E., of Dublin, Ireland.
ROWE, John Albert, of Enfield, Middlesex.
RUTTER, Peter Arthur, of Tadworth, Surrey.
SARDA, Shyamsunder, M.A.(Cantab.), of Dar-es-Salaam, Tanganyika.
SLOBOM, Geoffrey, of Woodthorpe, Notts.
STEEDMAN, James Cyril, of Brighton, Sussex.
STEER, Peter John, B.Sc.(Eng.), of Hounslow, Middlesex.
STEPHEN, Raymond James, of Cardiff.
STEVENS, Kenneth, of Totley, Sheffield.
STOBBS, Alfred, of West Ewell, Surrey.
SZE, Peter Piao, of Erith, Kent.
TAYLOR, Gordon Maurice, of Four Oaks, Warwickshire.
TOFTS, Richard Nicholas Hailey, of Grays, Essex.
TOON, Maurice Naldrett, of London.
VECK, Griffith Alan, of Kingston-on-Thames, Surrey.
VIGAR, Peter George, of London.
WALKER, Geoffrey Charles, of Tamworth, Staffs.
WHITBY, Laurence Peter, of Watford, Herts.
YOUNG, John Frederick, of Hornchurch, Essex.

FORTHCOMING MEETINGS

The following meetings will be held at 11, Upper Belgrave Street, London, S.W.1.

Thursday, 14th December, 1961

Ordinary Meeting, 6 p.m. "The Chemical and Physical Effects of Aggressive Substances on Concrete" by Dr. P. E. Halstead, B.Sc., F.R.I.C.

Thursday, 21st December, 1961

Ordinary General Meeting for the election of members, 5 p.m.

Thursday, 11th January, 1962.

Ordinary Meeting 6 p.m., "Structural Engineering Aspects of the Vickers House, Millbank, London," by Mr. Colin Davies, B.Sc., A.M.I.Struct.E., A.M.I.C.E.

Thursday, 25th January, 1962.

Ordinary General Meeting for the election of members at 5.55 p.m., followed by an Ordinary Meeting at 6 p.m., when a paper on "An Investigation into the Cause of Damage to the Severn Railway Bridge" will be given by Mr. Peter Mason, B.Sc.(Hons.), M.I.Struct.E., M.I.C.E. (Member of Council).

Thursday, 8th February, 1962.

Ordinary Meeting 6 p.m., "Failure of Structures During Erection or Demolition" by Mr. W. D. Short, B.Sc.(Civil Engineering).

Thursday, 22nd February, 1962.

Ordinary General Meeting for the election of members at 5.55 p.m., followed by an Ordinary Meeting at 6 p.m., when a paper on "Reconstruction of the Angel Road Bridge" will be given by Mr. John Mason, B.A.(Cantab.), M.I.Struct.E., A.M.I.C.E.

Members wishing to bring guests to the Ordinary Meetings announced above are requested to apply to the Secretary for tickets of admission.

EXAMINATIONS, JANUARY, 1962.

The Examinations of the Institution will next be held in the United Kingdom and overseas on the 9th and 10th January, 1962 (Graduateship) and the 11th and 12th January, 1962 (Associate-Membership).

PRIZES—JULY, 1961 EXAMINATIONS

The Council have awarded the following prizes in respect of the Examinations held in July, 1961.

ANDREWS PRIZE—For the candidate who obtains the highest aggregate of marks in Section 'A' of the Associate-Membership Examination, passing in both subjects:
D. W. WOOLGAR of Haslemere.

HUSBAND PRIZE—For the candidate who, having passed at one attempt in both subjects in Section 'A' of the Associate-Membership Examination, obtains the highest marks in Section 'B':
J. P. PRODROMOS of Beirut.
C. J. DAVIS of Woking.

WALLACE PREMIUM (SENIOR)—For the candidate who passes the whole of Section 'A' of the Associate-Membership Examination and obtains the highest marks in the paper "Theory of Structures":
A. H. NAVKAL of Bombay.
S. N. PAL of Calcutta.

A. E. WYNN PRIZE—For the candidate of those submitting a reinforced concrete design who, having passed or been exempted from Section 'A,' obtains the highest marks in Section 'B' of the Associate-Membership Examination:
R. M. FENNER of Croydon.

GRAHAM WOOD PRIZE—For the candidate of those submitting a structural steelwork design who, having passed or been exempted from Section 'A,' obtains the highest marks in Section 'B' of the Associate-Membership Examination:
S. MERRAN of Enfield.

WALLACE PREMIUM (JUNIOR)—For the most successful candidate in the Graduateship Examination, passing in all subjects:
ROGER AH-KEE of London.

REPORT ON THE STRUCTURAL USE OF ALUMINIUM

The Institution's Report on the Structural Use of Aluminium will be published shortly, price 7s. 6d. Corporate members may obtain one copy free on request and further copies at half the published price.

Branch Notices

LANCASHIRE AND CHESHIRE BRANCH

The following meetings have been arranged :—

Wednesday, 6th December, 1961

" The Plastic Design of Steel Framed Structures," by Professor M. R. Horne, M.A., Sc.D., Ph.D., A.M.I.C.E.

Thursday, 18th January, 1962

Junior Members Evening at the Royal Technical College, Salford.

Wednesday, 31st January, 1962

" The Economic Design of Shed Type Buildings, with Special Reference to the Use of the Plastic Theory," by Mr. S. Howell, M.I.Struct.E., at the Technical College, Bolton.

Tuesday, 13th February, 1962

" Motorways in Lancashire," by Mr. J. R. Ingram, A.M.I.C.E.

Wednesday, 28th February, 1962

Joint Meeting with the Institution of Civil Engineers. " The Lune Arch Bridge—Motorway M.6.—Lancaster," by Mr. T. W. Atherton, B.Sc., A.M.I.C.E., and Mr. F. W. Oliver, A.M.I.Struct.E., A.M.I.C.E., at 5.45 p.m. in the County Hall, Preston.

Unless stated otherwise, meetings will be held at the College of Science and Technology, Manchester, commencing at 6.30 p.m., preceded by light refreshments.

MERSEYSIDE PANEL

Wednesday, 13th December, 1961

" The Construction of a Large Covered Reservoir," by Mr. J. W. Baron, M.I.Struct.E., at the College of Building, Clarence Street, Liverpool.

Tuesday, 16th January, 1962

" Recent Trends and Developments in Three-Dimensional Frameworks," by Dr. Z. S. Makowski, Dipl.Eng., D.I.C.

Thursday, 15th February, 1962

" Report on a visit to Brazil, Venezuela and Mexico," by Dr. D. D. Matthews, M.A., M.Sc.(Eng.).M.I.Struct.E., M.I.C.E., (Vice-President).

Meetings will commence at 6.30 p.m., preceded by light refreshments, and will be held, unless stated otherwise, at Liverpool University, in the New Civil Engineering Building, Brownlow Hill.

Joint Hon. Secretaries : W. S. Watts, M.I.Struct.E., A.M.I.C.E., 11, Newchurch Lane, Culcheth, Nr. Warrington, Lancs., and M. D. Woods, A.M.I.Struct.E., 8, Dennison Road, Cheadle Hulme, Cheshire.

MIDLAND COUNTIES BRANCH

The following meetings have been arranged :—

Friday, 1st December, 1961

" The Structural Design of a New Store for Rackhams (Harrods) Ltd., in Birmingham," by Mr. F. G. Coffin, A.M.I.Struct.E., and Mr. J. N. Martin, A.M.I.Struct.E., A.M.I.C.E.

Tuesday, 5th December, 1961

Joint Meeting with the East Midlands Local Association of the Institution of Civil Engineers : " Vibration Problems in Relation to Foundation Design and Construction," by Mr. J. H. A. Crockett, B.Sc.(Eng.), D.I.C., M.Cons.E., A.M.I.Struct.E., A.M.I.C.E., at the East Midlands Electricity Board Demonstration Theatre, Irongate, Derby, at 6.15 p.m., preceded by refreshments from 5.30 p.m.

Tuesday, 30th January, 1962

Joint Meeting with the Warwickshire, Worcestershire and South Staffordshire Branch of the Royal Institution of Chartered Surveyors : " Have Quantity Surveyors and Structural Engineers any Common Interests ? " by Mr. I. F. Barrell, F.R.I.C.S.

Unless stated otherwise, meetings will be held in the Byng Kenrick Suite at the College of Advanced Technology, Gosta Green, Birmingham, at 6.30 p.m., preceded by tea from 5 to 5.45. p.m.

Hon. Secretary : A. N. Jones, B.Sc.(Eng.), A.M.I.Struct.E., A.M.I.Mech.E., 4, Sunny Bank Road, Quinton, Birmingham, 32.

GRADUATES' AND STUDENTS' SECTION

Friday, 8th December, 1961

" Recent Research in Timber Engineering," by Mr. I. D. G. Lee, B.Sc.(Eng.).

Friday, 5th January, 1962

" Elevated Roadways," by Mr. G. B. Smedley, B.Sc.(Tech.), A.M.I.Struct.E., A.M.I.C.E.

Friday, 2nd February, 1962

Film Show and Social Evening at the New Inns Hotel, Holyhead Road, Handsworth, Birmingham, 7 p.m.

Unless stated otherwise, meetings will be held at the Engineering Centre, Birmingham, and will commence at 6.30 p.m., preceded by tea from 6 p.m.

Hon. Secretary : R. J. Birch, B.Sc., (Graduate), 54, Quinton Lane, Birmingham, 32.

NORTHERN COUNTIES BRANCH

The following meetings have been arranged :—

Tuesday, 5th December, 1961

At Middlesbrough. " The Runcorn-Widnes Bridge," by Mr. J. K. Anderson, M.A., M.I.C.E.

Wednesday, 6th December, 1961

At Newcastle. " Some New Developments and Applications of Prestressed Concrete," by Mr. H. Kaylor, B.Sc.(Tech.), M.I.Struct.E., M.I.C.E.

Wednesday, 10th January, 1962

At Middlesbrough. Joint Meeting with the Tees-side Branch of the Northern Counties Association of the Institution of Civil Engineers : " Engineering Support to the Christmas Island Nuclear Tests of 1958," by Brigadier R. B. Muir, R.E., C.B.E., B.Sc., M.I.Struct.E., M.I.C.E., A.M.I.Mech.E., A.M.I.E.E.

Tuesday, 30th January, 1962

At Sunderland Technical College. " Concrete—its Materials and Making," by Mr. W. J. Henderson, M.I.C.E.

Tuesday, 6th February, 1962

At Middlesbrough. " Model Methods with Particular Reference to Three Recent Applications in the Fields of Steel, Composite and Concrete Construction," by Professor S. R. Sparkes, M.Sc., Ph.D., M.I.Struct.E., M.I.C.E.

Wednesday, 7th February, 1962
The above paper will be repeated at Newcastle.

Tuesday, 27th February, 1962
At King's College, Newcastle. "Modern Structural Steelwork Practice," by Mr. J. Ross.

Meetings will commence at 6.30 p.m., preceded by buffet tea at 6 p.m. Unless stated otherwise, meetings in Newcastle will be held at the Neville Hall, and those in Middlesbrough at the Cleveland Scientific and Technical Institution.

Hon. Secretary: P. D. Newton, B.Sc.(Eng.), M.I.Struct.E., A.M.I.C.E., 6, Cornfield Road, Linthorpe, Middlesbrough, Yorks.

NORTHERN IRELAND BRANCH

The following meetings have been arranged :—

Tuesday, 5th December, 1961
"Model Methods," by Professor S. R. Sparkes, M.Sc., Ph.D., M.I.Struct.E., M.I.C.E.

Tuesday, 9th January, 1962
"Design and Construction of a Shell Roof," by Mr. S. O. Morton, B.Sc., M.I.Struct.E., M.I.C.E.

Tuesday, 6th February, 1962
"A History of Structural Engineering," by Mr. P. S. Rhodes, A.M.I.Struct.E., F.G.S.

Meetings will be held in the David Keir Building, Civil Engineering Department, Queen's University, Belfast, at 6.30 p.m., preceded by tea from 5.45 p.m.

Hon. Secretary: L. Clements, A.M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E., 3, Kingswood Park, Cherryvalley, Belfast.

SCOTTISH BRANCH

The following meetings have been arranged :—

Tuesday, 5th December, 1961
"Crane Erection Problems," by Mr. W. H. Arch, B.Sc., A.M.I.C.E.

Friday, 15th December, 1961
Joint Meeting with the Glasgow and West of Scotland Association of the Institution of Civil Engineers: "Cable Spinning on the Forth Road Bridge," by Mr. H. Shirley Smith, O.B.E., B.Sc., M.I.C.E.

Monday, 22nd January, 1962
"The 300 ft. Span R.C. Arch Bridge at Howford, Ayrshire," by Mr. W. A. Fairhurst, C.B.E., M.I.Struct.E.

Friday, 16th February, 1962
"Aspects of Field Testing in Soil Mechanics," by Mr. H. B. Sutherland, S.M., F.R.S.E., A.M.I.Struct.E., A.M.I.C.E.

Meetings will be held in the Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, at 7 p.m.

EDINBURGH SECTION

Tuesday, 16th January, 1962
"Structural Application of Tubes and Rectangular Hollow Sections," by Mr. G. B. Godfrey, A.M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E., (Associate-Member of Council).

Tuesday, 20th February, 1962
Joint Meeting with the Edinburgh Architectural Association: "Some Aspects of Multi-storey Construction in Scandinavia," by Mr. T. H. Haddow, M.I.Struct.E., M.I.C.E., A.R.I.B.A.

Meetings will be held at the Heriot-Watt College, Edinburgh, at 6 p.m.

Hon. Secretary: W. Shearer Smith, M.I.Struct.E., A.M.I.C.E., c/o The Royal College of Science and Technology, George Street, Glasgow, C.1.

SOUTH AFRICA BRANCH

Hon. Secretary: E. B. Kretschmar, A.M.I.Struct.E., P.O. Box 3306, Johannesburg, South Africa.
Natal Section Hon. Secretary: E. G. Bennett, A.M.I.Struct.E., P.O. Box 932, Durban.
Cape Section Hon. Secretary: R. F. Norris, A.M.I.Struct.E., African Guarantee Building, 8, St. George's Street, Cape Town.

SOUTHERN BRANCH

The following meetings have been arranged :—

Friday, 1st December, 1961
"Instability of Thin-Walled Members," by Dr. P. S. Bulson, B.Sc., A.M.I.Struct.E., A.M.I.Mech.E.

Friday, 26th January, 1962
"Swedish Practice in the Construction of Multi-Storey Reinforced Concrete Flats," by Mr. H. E. Lewis, M.Sc., D.I.C., and Mr. G. S. Rendall.

The meetings will be held in the Main Lecture Theatre, Lanchester Building, University of Southampton, at 6.30 p.m., preceded by tea in the Refectory (West Site) from 6 p.m.

Hon. Secretary: A. P. K. Tate, B.Sc.(Eng.), Ph.D., A.M.I.Struct.E., Department of Civil Engineering, The University, Southampton.

WALES AND MONMOUTHSHIRE BRANCH

The following meetings have been arranged :—

Monday, 4th December, 1961
At Cardiff. "Structural Steelwork at Spencer Works," by Mr. A. V. Hooker, M.I.Struct.E., M.I.C.E., (Past Chairman) and Mr. C. J. E. Morris, M.A., A.M.I.C.E.

Friday, 15th December, 1961
At Swansea University. Joint Meeting with the South Wales and Monmouthshire Branch of the Institution of Civil Engineers: "The Design of Reinforced Concrete through the Use of Plastic Models," by Mr. B. W. Preece, B.Sc.

Wednesday, 31st January, 1962
At Swansea. Joint Meeting with the South Wales Institute of Architects and the Reinforced Concrete Association: "Application of the Pretensioned Plate Technique," by Mr. F. Adler, B.Sc.(Eng.), A.M.I.Struct.E.

Tuesday, 20th February, 1962
At Cardiff. Joint Meeting with the South Wales and Monmouthshire Branch of the Institution of Civil Engineers: "Recently Developed Techniques for Structural Analysis—The Use of Computers," by Professor P. B. Morice, D.Sc., Ph.D., A.M.I.Struct.E., A.M.I.C.E.

Unless stated otherwise, meetings in Cardiff will be held at the South Wales Institute of Engineers, Park Place and those in Swansea at the Mackworth Hotel, and will commence at 6.30 p.m.
Hon. Secretary: W. D. Hollyman, A.M.I.Struct.E., 41, Greenfield Avenue, Dinas Powis, Glamorgan.

WESTERN COUNTIES BRANCH

The following meetings have been arranged :—

Friday, 1st December, 1961
Special Meeting to which kindred professional and technical bodies will be invited: "Long Span Suspension Bridges with Reference to the Severn Bridge," by Mr. M. F. Parsons, B.Sc., A.M.I.C.E.

Friday, 5th January, 1962

"A Mobile Tower for Servicing Rockets," by Mr. F. K. Fennell, A.M.I.Struct.E.

Friday, 2nd February, 1962

Students and Graduates Evening. "Waterproofing of Sub-Structures," by Mr. H. Bryan, A.M.I.C.E., and "Composite Construction Applied to a Development at Keynsham, Somerset," by Mr. T. Limna.

Tuesday, 13th February, 1962

ANNUAL DINNER DANCE at the Ashton Court Country Club, Failand, Bristol, 7.30 p.m.—1 a.m.

Unless stated otherwise, meetings will be held at Queen's Building, University Walk, Bristol, the December one in the Large Lecture Theatre, the January and February ones in the Small Lecture Theatre. They will commence at 6 p.m. and will be preceded by a light tea at 5.30 p.m.

Hon. Secretary: M. S. G. Cullimore, B.Sc., Ph.D., A.M.I.Struct.E., Queen's Building, University Walk, Bristol, 8.

YORKSHIRE BRANCH

The following meetings have been arranged :—

Wednesday, 13th December, 1961

At Leeds. Joint Meeting with the Yorkshire Association of the Institution of Civil Engineers and the Yorkshire and Lincolnshire Branch of the Institution of Highway Engineers: "The Doncaster Motorway—Reflections in Retrospect," by Mr. S. Maynard Lovell, O.B.E., T.D., M.I.C.E., M.I.Mun.E.

Wednesday, 17th January, 1962

At Leeds. "The Chemical and Physical Effects of Aggressive Substances on Concrete," by Dr. P. E. Halstead, B.Sc., F.R.I.C.

Wednesday, 7th February, 1962

At Sheffield. "The Structural Engineer in the Coal Industry," by Mr. C. A. C. Davies, M.I.C.E.

Wednesday, 21st February, 1962

At Leeds. "The Design and Construction of the Millbank Development Tower Block," by Mr. Colin Davies, B.Sc., A.M.I.Struct.E.

Meetings in Leeds will be held at the Metropole Hotel, King Street and those in Sheffield at the Royal Victoria Hotel, and will commence at 6.30 p.m., preceded by buffet tea at 6.15 p.m.

Hon. Secretary: W. B. Stock, A.M.I.Struct.E., 34, Hobart Road, Dewsbury, Yorks.

SECTION NOTICES

AUCKLAND (NEW ZEALAND) SECTION

Hon. Secretary: A. Donald, B.Sc.(Hons.), A.M.I.Struct.E., 122, Matipo Road, Te Atatu, Auckland, New Zealand.

EAST AFRICAN SECTION

Hon. Secretary: K. C. Davey, A.M.I.Struct.E., P.O. Box 30079, Nairobi, Kenya.

NIGERIAN SECTION

Hon. Secretary: A. Brimer, M.I.Struct.E., Brimer, Andrews & Nachshen, Private Mail Bag, 2295, Lagos, Nigeria.

REPUBLIC OF IRELAND SECTION

Hon. Secretary: P. J. Carroll, M.E., A.M.I.Struct.E., A.M.I.C.E., A.M.I.C.E.I., 9, Laburnum Road, Clonskea, Dublin, Ireland.

SINGAPORE AND FEDERATION OF MALAYA SECTION

Hon. Secretary: J. R. M. MacIntyre, A.M.I.Struct.E., c/o Redpath, Brown & Co. Ltd., P.O. Box 648, Singapore.

SOUTH WESTERN COUNTIES SECTION

The following meetings have been arranged :—

Friday, 8th December, 1961

"Site Production and Placing of Concrete," by Mr. R. J. Tatt, A.M.I.C.E.

Friday, 5th January, 1962

Joint Meeting with the Institution of Civil Engineers: "Aluminium Structures with Particular Reference to Bridges," by Mr. R. M. Davis, B.Sc., A.M.I.C.E.

Meetings will be held at the Duke of Cornwall Hotel, Plymouth, at 6 p.m., preceded by tea at 5.30 p.m.

Hon. Secretary: C. J. Woodrow, J.P., M.I.Struct.E., "Elstow," Hartley Park Villas, Tavistock Road, Plymouth, Devon.

CORRIGENDA

SESSIONAL PROGRAMME 1961-1962

p. 58. South-Western Counties Section: The Chairman's Address will be given by Mr. J. D. Norfolk, M.I.Struct.E., M.I.C.E., M.I.Mun.E., and not as shown.

p. 48. Yorkshire Branch: Committee Member Mr. L. Preston should be shown as Past Chairman.

The Structural Engineer, October, 1961

"Some note on the Fatigue Resistance of Corroded Prestressing Wire," by A. Goldstein and C. F. Brereton, p. 337: In Table 4, the first two lines should read as follows :—

pH of solubles		
Soluble chlorides reported as		
	4-4·5	
Cl	·75	Tons/sq.mile/month.

BOOK REVIEW

Introductory Soil Mechanics and Foundations, 2nd Edition, by G. B. Sowers and G. F. Sowers. (New York: The MacMillan Company, 1961) 9½ in. × 6 in., 386 plus xiii pp., 56s.

Since the first edition of this book appeared ten years ago there have been many changes in methods for analysis and design, so that it was found necessary to revise the original text completely, over two-thirds of which has been rewritten. This is an essentially practical book which deals thoroughly with the nature, properties and geology of soil, and, in the second edition, an even greater emphasis has been given to the basic principles that govern soil behaviour, and the importance of the relation of mineralogy, physico-chemical forces and structure to shear strength, consolidation, compaction and soil stabilisation. More space has been given to the application of the basic principles to foundation analysis and design and the sections dealing with bearing capacity of shallow foundations and with piles and piling are brought up to-date. Further material has also been included on drainage, soil expansion, anchored bulkheads, stability and earth dam design.